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A Hydrogeological Study of the Selkirk Area, Manitoba

J. E. Charron

SCIENTIFIC SERIES NO. 8
(Résumé en français)

*INLAND WATERS DIRECTORATE,
WATER RESOURCES BRANCH,
OTTAWA, CANADA, 1974.*

Dye tracing was one of the methods used in the course of the Selkirk hydrogeological survey to determine the direction and velocity of groundwater flow. In the upper picture, water dyed with the vegetable dye, sodium fluorescein, flows from an extraction well at the Tyndall Project. Clear water can be seen flowing from the pipe at top centre. In the lower picture, the pool formed by Poplar Spring measures 70 feet by 60 feet and is seven feet deep at its greatest depth.

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Cat. No.: En 36-502/8

Contract # KL 398-4-8203
THORN PRESS LIMITED

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Abstract

This report describes the last of six groundwater studies carried out by the writer in the Red River Valley, Manitoba. The study consisting mainly of a well inventory of over 3,000 wells in the Selkirk map-area, was carried out during the summers of 1964 and 1965. The groundwater yield of the various aquifers is described both quantitatively and qualitatively. In the Selkirk map-area, there is evidence of a more abundant supply of groundwater of good quality than exists in any of the other areas in the Red River Valley studied by the author.

The Selkirk area loses by natural discharge from one spring alone (Poplar Spring), 2 ½ million Imperial gallons per day (Igpd) of good, hard, potable groundwater [total dissolved solids (TDS) 382 ppm (parts per million)]. This is more than the total consumption of water from all the wells in the area, with the exception of one industrial well. Obviously, the groundwater potential of the Selkirk area falls far short of being fully exploited.

The direction of groundwater flow in the area is demonstrated by hydrogeochemistry, using Schoeller's semi-logarithmic diagrams and the hydrochemical zonation method. The effect of the process of reverse osmosis is explained. Dye tracer experiments carried out at two different sites to determine groundwater flow direction and velocity on a local scale are described.

The report includes a description of an area in which gas exhalations (mainly CO_2) occur with variation in barometric pressure and suggests that, as the groundwater of this area has a lower than normal piezometric surface, the possibility of artificial recharge exists.

Résumé

Ce rapport décrit la dernière de six études des eaux souterraines entreprises par l'auteur dans la vallée de la rivière Rouge (Red River), au Manitoba. L'étude, consistant principalement en un inventaire de plus de 3,000 puits dans la région de Selkirk, a été effectuée au cours des étés 1964 et 1965. Les eaux souterraines obtenues des différentes formations aquifères sont décrites à deux points de vue, quantitativement et qualitativement. Dans la région de Selkirk, il y a une évidence de plus grandes ressources en eaux souterraines de bonne qualité, comparativement à toutes les autres régions étudiées par l'auteur, dans la vallée de la rivière Rouge au Manitoba.

La région de Selkirk perd par l'écoulement naturel d'une seule source (Poplar Spring), environ 2 ½ millions de gallons impériaux par jour, de bonne eau souterraine, dure et potable (total des sels dissous, 382 ppm). Ceci est plus que l'usage total de l'eau de tous les puits de la région, faisant exclusion d'un puits industriel. Il est clair que le potentiel en eaux souterraines de la région de Selkirk est loin d'être entièrement exploité.

La direction d'écoulement d'eaux souterraines de la région est démontrée par la méthode hydrogéochimique, utilisant les diagrammes semi-logarithmiques de Schoeller et la méthode de zonage hydrochimique. L'effet du processus d'osmose inverse est expliqué. On décrit des expériences faisant usage de teintures végétales, à deux emplacements différents, faites dans le but de déterminer la direction et la vitesse d'écoulement des eaux souterraines à l'échelle locale.

Le rapport inclut la description d'une région dans laquelle des exhalaisons de gaz (principalement de CO_2) se produisent quand il y a changement dans la pression atmosphérique, et suggère que les eaux souterraines de cette région ayant une surface piézométrique plus basse que la normale, il y a possibilité d'une alimentation artificielle des nappes aquifères.

Introduction

The main purpose of this study was to collect a body of well inventory data and to use these data in determining the amount and quality of groundwater in the Selkirk area of Manitoba. In addition to the standard methods used, two field tests using vegetable dyes were carried out to determine the direction and velocity of groundwater flow. The results of these tests have local rather than general application. Hydrochemistry is also employed to determine the direction of groundwater movement as well as to show the hydrogeological relationship between the various bedrock formations and the groundwater.

LOCATION

The study area is immediately north of Winnipeg and extends north from Township 13 to Township 18 on the west side of Lake Winnipeg and from Township 13 to Township 20 on the east side of Lake Winnipeg (Figs. 1 and 2). From the Principal Meridian, the area extends east to Range 12E. The total area is approximately 2,600 square miles.

PHYSIOGRAPHY

Hydrogeologically, the region appears to be a discharge area with Lake Winnipeg (elevation 713′ above sea level) the lowest point on the map-sheet. The region is divided into two distinct parts by Lake Winnipeg in the north and the Red River in the south. Topographically, the west side slopes fairly uniformly in an easterly direction from a high of 900′ above sea level in the Interlake region to the Red River and Lake Winnipeg. The topography on east side is more irregular, sloping generally from east to west. The main features include a second large stream, the Winnipeg River, in the eastern portion of the map-sheet, and nine individual topographical highs with elevations ranging from 850′ a.s.l. to 1,000′ a.s.l. which dominate the eastern half of the area. As groundwater movement and water table elevation are controlled to some extent by topography, these nine topographic highs will figure prominently in explanations of the hydrogeology of the eastern half of the map-area. The fact that they are also recharge areas adds to their importance.

The nine hills (Fig. 3) can be divided into three groups. One group, consisting of Hills 3, 4, 5, 6, 7 and 8, lies west of the main 800′ contour and along the east and southeast shores of Lake Winnipeg. This group could be considered as extending further to the southwest as far as Bird's Hill (Tp. 12, Rge. 5, outside map-area), because geographically as well as topographically Bird's Hill aligns itself perfectly with the six hills in this group.

The second group, consisting of Hills 1 and 9, is east of the 800′ contour line and west of the Winnipeg River. This group also could be considered as extending to the south to align with a topographic high in Tp. 12, Rge. 10E.

Hill 9 is on the east side of the Winnipeg River.

Geologically, the nine hills are very similar in that they consist of glacial outwash deposits of sand and gravel.

Lake Winnipeg

Only the southern portion of Lake Winnipeg is dealt with in this report. The extreme southern end of the lake, forming the delta of the Red River, is flat and marshy. The land on the west side is low and rises gradually westward from the beach. On the east side, the land rises abruptly at the beach, forming cliffs 20 to 30 feet high, particularly in Tp. 19. Both shores consist mainly of till.

DRAINAGE

The two principal rivers in the area, the Red and the Winnipeg, flow generally in a northerly direction to Lake Winnipeg. The central plain of the eastern part of the area is drained to Lake Winnipeg by the Brokenhead River. Natural drainage in the western portion of the map-area is poor, particularly in the northwest corner where the till plain consists mainly of elongated sloughs. Most of the drainage in the western portion is handled by man-made drainage ditches.

CLIMATE

The climate is continental with a mean annual temperature of 39°F. The mean annual precipitation is 20 inches. In 1964, the year in which the field study of the east side of the map-area was carried out, the frost-free period was one of the shortest on record. Except for keeping the static water level somewhat lower than normal, at least at the beginning of the study early in June, the hydrogeological study was not affected.

Geology

INFILTRATION MAP

Figure 1 is a surficial geology map derived from agricultural soil maps (Winnipeg area 1954, Toulon area 1961, and the preliminary soil map of Lac du Bonnet 1964). These soil maps have been modified by the author to assist in an understanding of the hydrogeology of the area. The surficial deposits shown on Figure 1 have been grouped in three main classes: clay, till and sand and gravel.

Clay

Generally lowest in elevation are the extremely flat clay areas, which are the remains of the lake sediment deposits of glacial Lake Agassiz. There are three main clay regions (Fig. 1). One of these follows the course of the Red River to its mouth and includes the delta. A second occupies the central portion of the west side of the map-area and the third is centrally located on the east side of the area. A fourth, much less extensive, clay plain follows the course of Winnipeg River.

Hydrogeologically speaking, these clay deposits are considered almost completely impermeable and were it not for the man-made drainage ditches, what are now fertile plains would be nothing but swamps and marshes. As they are associated with topographical lows, they can be classified as discharge areas. Consequently, many springs are found along these clay deposits, especially on the west side of the map-area. The maximum clay depth encountered in the area was 80 feet.

Till

The till commonly known as hard pan is a ground moraine that covers almost the entire area except where rock outcrops. Where it is not exposed at the surface, it underlies the clay. The west side of the Selkirk area towards the Interlake region is a ground moraine consisting of elongated ridges and adjacent long narrow sloughs. Each ridge acts as a dam between two sloughs. The pattern of ridges and sloughs trends in a northwest — southeast direction, reflecting the direction of movement of the glacial ice which formed them.

The composition of the till reflects the underlying bedrock. On the east side of the area, the bedrock is granitic and this is reflected in the quartz and feldspar that predominate in the till. On the west side, the whitish calcareous appearance of the till reflects the dolomitic limestone bedrock.

Figure 1 indicates the presence of three till lenses at the surface. In addition to the two referred to above, one on the west side and one on the east side of the map-area, a third till lens extends northwestward from the south central area of the map. This third lens divides into two components at the southern extremity of Lake Winnipeg, one component following the west shore of the lake and the other the east shore. The till matrix of the southern portion of the third till lens is more clayey than at any other place in the till in the entire Selkirk area, except possibly in till deposits adjacent to the Winnipeg River.

From the groundwater standpoint, the ground moraine type of till deposit, just described is classified as semipermeable. The thickness of the till varies generally from 25 to 75 feet and in some places is as much as 100 feet thick. The till areas can be considered as long-term recharge areas with slow infiltration rates compensated for by large areal extent.

Sand and Gravel

Finally there are the permeable surficial deposits of sand and gravel. Figure 1 differentiates between the large deposits of sand and gravel and the less extensive but predominantly gravelly deposits. The large deposits, especially the nine hills on the east side, are believed to be outwash deposits. Many of the long, narrow deposits are remnants of the beach deposits of glacial Lake Agassiz (Johnston 1934).

These permeable areas of sand and gravel are the only true direct recharge areas on the infiltration map. Compared to the semi-permeable till deposits, they can be classified as short-term recharge. The elongated gravelly beach deposits are usually shallow with thicknesses from 10 to 15 feet while the large outwash deposits can be as much as 75 feet thick. The north side of the large outwash deposits appears to contain more large boulders than any other part of the hill. This was particularly noticeable on Hill 4 north of Stead in Tp. 17, Rge. 8E.

Most of the gravel beaches on the west side of the area and extensive sections of the nine sand and gravel hills on the east side have been dug up as gravel pits. While there are sound commercial reasons for exploiting these deposits, the effect has been to reduce the recharge capacity of the area, thereby affecting the long-term availability of groundwater in the Selkirk area.

In summary, therefore, the infiltration map shows that large impermeable areas consisting of clay deposits will not allow infiltration while an equally large area of till (three lenses in all) offer steady long-term groundwater recharge to the Selkirk area. Immediate direct recharge from precipitation occurs mainly where large sand and gravel areas exist.

BEDROCK GEOLOGY

Precambrian rocks (granite) underlie the surficial deposits of the Selkirk area from Rge. 8E eastwards and there are numerous outcrops. The westernmost outcrop, in Sec. 3, Tp. 14, Rge. 8E (Fig. 1), is the last granite outcrop at this latitude short of the Rocky Mountains. In this study, the granite is considered impermeable and wherever large granite outcrops protrude from the till, they tend to form swamps by damming surface water, particularly where the topography is relatively flat.

From Rge. 8E westward, the surficial deposits are underlain by rocks of Ordovician age. The boundary between the Ordovician and Precambrian rocks is shown on Figure 2. A revised sequence of Ordovician rocks (Sinclair 1959) is tabulated on this page.

Stonewall Formation		Dolomite
Story Mountain Formation	Gunton Member Penitentiary Member Gunn Member	Dolomite Argillaceous dolomite Calcareous shale
Red River Formation	Cat Head Member	Alphanitic limestone and dolomite, with chert
	Dog Head Member	Fragmental limestone with dolomite mottling
Winnipeg Formation		Sandstone and shale

Along the eastern boundary of the Ordovician rocks, the Winnipeg Formation overlies the granite, but at no place in the entire map-area does it outcrop at the surface. Information on this formation, therefore, will be derived exclusively from drill-hole data. The formation is made up of shale and sandstone beds. The sandstone bed is considered in this study to be the aquifer part of the formation and is approximately 20 to 25 feet thick.

The Winnipeg Formation in turn is overlain by the Red River Formation. The latter consists mostly of limestone and dolomite. It does not outcrop at the surface, but is close enough to the surface to be seen in the Tyndall limestone quarries in Tp. 13, Rge. 6E and also at Stonewall and vicinity in Tp. 13, Rges. 1E and 2E (Fig. 1). The proximity of the Red River Formation to the surface is reflected also by two sink holes in Secs. 12 and 13, Tp. 13, Rge. 6E. The Red River Formation is a very good aquifer for two reasons. First, it is a very extensive and very thick porous limestone formation (up to 242 feet thick in a well at Selkirk and over 400 feet thick in Tp. 14, Rge. 1E), and is well fractured, especially in its weathered zone immediately below the surficial deposits. Second, its proximity to the surface helps keep drilling costs down. The Red River Formation, therefore, can be considered to be the best aquifer in the area.

Overlying the Red River Formation are the dolomites of the Stony Mountain and Stonewall Formations. These rocks can be considered to be part of the Red River Formation because the three formations are so similar that they cannot be separated in drill-hole logs and correlation is possible only through palaeontological investigation (Stearn 1956). The dolomites can be considered good aquifers.

The entire sedimentary bedrock complex dips southwestward at approximately 10^0.

Hydrogeology

DUG WELLS, SPRINGS AND DRILLED WELLS

During the course of this study, well inventory data were compiled for over 3000 wells. The location of each well is shown on Figure 4. Those surveyed in 1964 are numbered 1 to 1,303, and are confined to the area east of the line dividing Rges. 5E and 6E; the wells surveyed in 1965 are numbered 1 to 1,961 and are confined to the area west of this line. Where the wells are too numerous to be illustrated clearly on Figure 4, they are shown on the larger-scale map supplements on Figure 5.

Most of the wells are west of the contact of the sedimentary and Precambrian rocks (Figs. 2 and 4), and most are drilled wells. The shallow dug wells (water-table wells) are located for the most part in the eastern half of the area where the surficial deposits are underlain by the Precambrian granite. This indicates that the granite is a very poor aquifer or aquiclude and is the reason the Precambrian granite has been classified, for the purposes of this report, as impermeable.

It is interesting to compare population (as reflected by well density) in the clay plain on the east side and population in the otherwise similar clay plain on the west side. It can be seen from Figure 4 that settlement in the eastern plain (Rge. 8E) is considerably more extensive than in the western plain (Rge. 3E). It will be shown later that groundwater and drainage account for the difference.

Forty-four springs were mapped in the Selkirk area with the greatest concentration occurring along the 775-foot contour. Eighteen springs occur at that elevation on both sides of the map-area (Figs. 3 & 4). The springs appear at the surface along or near the till-clay contact. The occurrence of large springs in the clay plains is explained by the fact that the clay layer is thin (less than 18 feet) and the water pressure is high enough to force its way through. At these points, the clay matrix is probably a little more silty than in surrounding areas.

If a spring can be considered as the shallowest of wells, by contrast the deepest well drilled in the area is 640 feet deep (exploratory hole for oil in 6-13-6E). In NE 36-17-2E, a water well was drilled to a depth of 310 feet, the greatest depth drilled in the area for water. With a ground elevation of 850′ a.s.l., the bottom elevation would be 540′ a.s.l. A shallower well in the town of Selkirk has a bottom elevation of 425′ a.s.l., the lowest point in the entire map-area from which water is obtained. This point may be considered, therefore, the centre of the map-area. The water in the Selkirk well rises to an elevation of 694 feet a.s.l., or 269 feet higher than where it was encountered. The highest piezometric surface encountered on the west side of the area is in 33-16-1E at an elevation of 880 feet a.s.l. The highest water-table elevation on the west side was 899′ a.s.l. in 20-18-1E.

The corresponding values for the east side were 886′ a.s.l. for the highest piezometric surface encountered (in 36-13-9E) and 896′ a.s.l. for the highest water-table elevation (in 1-14-9E).

If the map-area is considered as a unit, the difference between the average of the highest piezometric surface elevations (west and east) and the lowest piezometric surface elevation is 189 feet, which gives an overall hydraulic gradient for the area of 0.72%. The actual gradient would be something less than 0.72% because the piezometric surface elevation of 694′ a.s.l. in the Selkirk well was slightly lower than normal due to the heavy demand on the confined aquifers by the town of Selkirk. It is to be expected that the gradient would be greater than 0.72% where the slopes are steep and less in the flat clay plains.

FLOWING WELLS

Figures 3 and 4 show the existence of many flowing wells in the area. On Figure 3, the non-flowing wells shown are restricted to those with a static water level of zero (water level at ground level). Most wells with zero surface water level flowed continually at some time in the past and some still overflow in years when the piezometric surface rises because of heavier-than-normal precipitation.

As many as 100 flowing wells were counted on the west side of the area and 159 on the east side. There were 21 wells with zero static water level on the west side and 114 on the east side. This means that about one tenth of the approximately 3000 wells for which data were made available by this well inventory are

flowing wells. Most of the flowing wells are in the same general areas and at the same elevation as the springs mentioned earlier. There are, however, two groups of flowing wells to which this does not apply. One group is located in Tp. 18, Rge. 2E at an elevation of 875′ a.s.l. This group probably extends to the north of the map-area and is probably very limited in extent. If it can be considered a discharge area, then it must be supplied by a nearby local recharge area. The second extends along the west shore of Lake Winnipeg in Tps. 17 and 18, Rge. 4E. This group is actually a continuation of the flowing zone found between the 750-foot and 775-foot contours. These wells flow at an elevation of between five and ten feet above the water-surface elevation of Lake Winnipeg (713′ a.s.l.), indicating that Lake Winnipeg is the ultimate discharge zone for that part of the map-area.

The fact that the piezometric level remains so high, as indicated by the large number of flowing wells and the fact that a large source of supply must be available to feed the natural springs and the flowing and non-flowing wells, provide ample evidence that large quantities of groundwater are available in the area.

GROUNDWATER OCCURRENCE

Groundwater in the Selkirk area can be encountered at one or more horizons depending on the location of the well.

From Rge. 8E to Rge. 12E, groundwater can be obtained by drilling into the Precambrian granite in the hope of encountering a fracture that will yield water. This method, however, should be used only as a last resort, where no other source of groundwater can be found in the surficial deposits overlying the granite. In the same area, the till itself can be considered as an aquiclude or at best a very poor aquifer. There are, however, thin lenses of silt, sand and gravel within the till which will yield water. This is the source of supply for the shallow-dug wells of this part of the map-area. The largest supply of groundwater available in the till is usually found at the till-bedrock contact. This is because the till at that horizon usually consists of coarse sand or gravel. Also, the bedrock is usually weathered at the contact and the chances are good that such a permeable zone will yield a fair amount of water. This holds true whether the contact is till-granite, till-sandstone, till-limestone or till-dolomite. This is well illustrated by the cross-sections of the east half of the map-area (Fig. 6).

Next to be considered are the glacial outwash deposits that make up the nine hills referred to earlier. On the hills themselves, groundwater can be obtained in the sand and gravel, but because these hills are recharge areas, the static water level (water table) will be quite low, as much as 40 to 45 feet below ground level. Good permeable sand and gravel deposits that are classified as good infiltration or recharge areas are not necessarily the best aquifers unless the deposits are very thick. Consequently, the best location for a well is where the sand and gravel disappear under the clay or till deposits. These locations will be in a belt situated at the base of each hill. On these points the recharge area changes from an unconfined aquifer to a confined aquifer, the clay or till acting as the confining layer. Under these conditions, the water will be under pressure and the flow will be more constant than would be the case where the well depends entirely on precipitation.

On the east side of the map-area, therefore, if the surface is till or clay, a well should normally be drilled to the till-bedrock contact. Drilling into the granite bedrock for a groundwater supply is not to be recommended unless all other means have failed. Near glacial outwash deposits, the best site for a well will be at the base of the hill.

In the western part of the map-area, the Ordovician dolomite and mottled limestone bedrock formations are the best aquifers. Their great thickness, extensive area, and proximity to the surface make them ideal aquifers. Water is usually encountered in fractures in the solid bedrock. In some areas, however, such as the northwest corners of Tps. 17 and 18, Rge. 1E and a very small area in the Parish of St. Peter (approximately Lot 203), the presence of a layer of red shale (possibly Stony Mountain Formation) may colour the water red. The shale bed usually occurs between the till and limestone or dolomite. As the water is supplied by the limestone or dolomite aquifer, it is recommended that when drilling in these areas, the casing be lowered into the aquiferous rock so as to completely seal off the red shale.

As is the case on the east side of the Selkirk map-area, the till-bedrock contact is a good source of groundwater. It is interesting to note that many well owners are under the impression that the groundwater yielded by their wells comes from the deep solid bedrock formations of limestone or dolomite, when in fact the groundwater supply is derived from the till-bedrock contact zone. In these cases the well was driven not into the solid bedrock but only to the bedrock contact or at most into the weathered zone.

The sandstone of the Winnipeg Formation is a good aquifer but, because it is far below ground (300′ + in the town of Selkirk), and drilling costs are correspondingly high, only commercial and government establishments make use of it. Although the aquifer is not very thick (25 feet), the amount of water available is sufficient to meet current demands. Any sizeable increase in these demands, however, could well lead to shortages.

Shallow water-table wells (dug, bored, or driven), exist over the entire map-area and wells of this type rely for their groundwater source mostly on the thin lenses of silt, sand or gravel found in the till. It may be of interest here to observe that the sites of most of the wells drilled in the Selkirk area were determined by water-witching or water-divining.

Groundwater — Quantitative Data

GROUNDWATER SUPPLY

With the exception of the eastern part which is underlain by Precambrian rocks, the groundwater supply is sufficient to satisfy present requirements. Figure 7 shows the distribution of groundwater in the Selkirk area. The lack of an adequate supply of groundwater in the eastern part of the area is compensated for by an abundance of surface water. A community such as Lac du Bonnet, for example, obtains its water supply from the Winnipeg River and this is true of most of the residences and farms situated along the river.

Lowest in terms of groundwater availability are the areas east of the Winnipeg River and in the vicinity of the Whitemouth River. In these areas, the wells yield generally less than one Imperial gallon per minute (Igpm). A smaller area with similar yield follows the east shore of Lake Winnipeg in Tp. 9. Next on the scale are two large areas, one underlain by granite, on the east side of the map-area and the other underlain by dolomitic rocks in the northwest corner of the map-area where the wells yield on the average one Igpm. Wells in the sand and gravel outwash deposits at the base of the hills yield on the average 10 Igpm. The highest yield in the entire Selkirk area is from springs, the largest of which are in Rges. 2E and 3E from Tps. 14 to 16. One of these springs, Poplar Spring, produces over 2½ million gallons per day. At the time this study was carried out, the water from these springs was not used except for watering a few cattle.

WELL YIELD

Dug Wells

Data accumulated on 575 dug wells showed that, over the entire area, the average depth was 23 feet with a water-table level 12 feet below ground (Figure 8). This means that the depth of water averaged 11 feet. A 4′-square well yields approximately one Igpm.

Dug wells were found to be shallower on the east side of the map-area, with depths averaging 19 feet as compared with 32 feet on the west side. The water table on the east side stood at 9.5 feet below ground compared with 20 feet on the west side. It is evident, therefore, that on the east side a dug well is more practical because of the shallow depths involved and because the granite bedrock is an aquiclude. On the west side, the most reliable supply of groundwater can be obtained by drilling to the till-bedrock interface or into the bedrock itself. The fact that there are 425 dug wells on the east side and only 150 on the west side supports this thesis.

Drilled Wells

There are five times as many drilled wells in the Selkirk area as there are dug wells. The average depth of a drilled well in the area is 80 feet. With the static water level averaging 19 feet below ground, there will be approximately 61 feet of water in the well (Figure 8). The piezometric surface of drilled wells in the area is, therefore, some 7 feet below the water table encountered in dug wells. Bedrock is approximately 46 feet below ground. Consequently, drilling a well will involve about 50 feet of casing. The average yield of a drilled well in the area will be 20 Igpm.

The figures in the preceding paragraph are average figures for the whole area. As was the case with dug wells, however, conditions on the east side differ from those on the west side.

On the east side, the average depth of a drilled well is 66 feet. The static water level is 7.9 feet below ground, or 1.6 feet higher than the water table. The average bedrock level is 42 feet below ground. The corresponding figures for the west side are: depth, 87 feet, static water level, 25 feet below ground; bedrock, 47 feet below ground. The piezometric surface on the west side is 5 feet below the water table. It is obvious therefore that, because of the greater depth involved and the greater length of casing required, it will cost more to drill a well on the west side than to drill one on the east side. The greater yield of drilled wells on the west side, however, will compensate for this. The yield of a drilled well on the west side will be 24 Igpm average, compared with 8.7 Igpm on the east side. The calculated transmissibility value of sedimentary rocks on the west side is 10,000 gpd/ft. and only 740 gpd/ft. on the east side. This means, therefore, that on the east side the maximum yield of a drilled well in the limestone of the Red River Formation is approximately 16 Igpm, while on the west side it can be as high as 300 Igpm. Deep wells in the town of Selkirk yield as much as 500 Igpm and

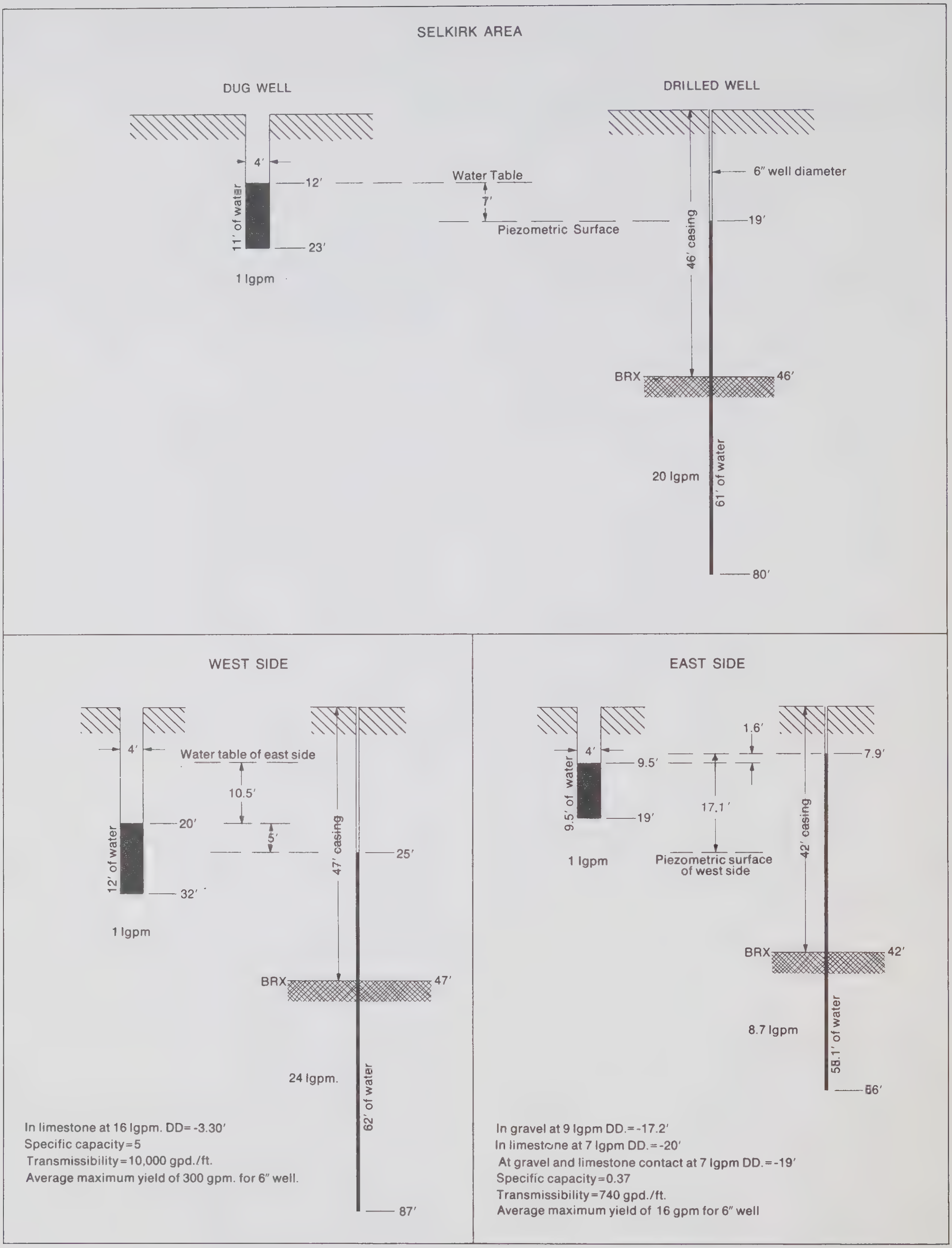

Figure 8 Statistical comparison and hydraulic characteristics of dug and drilled wells

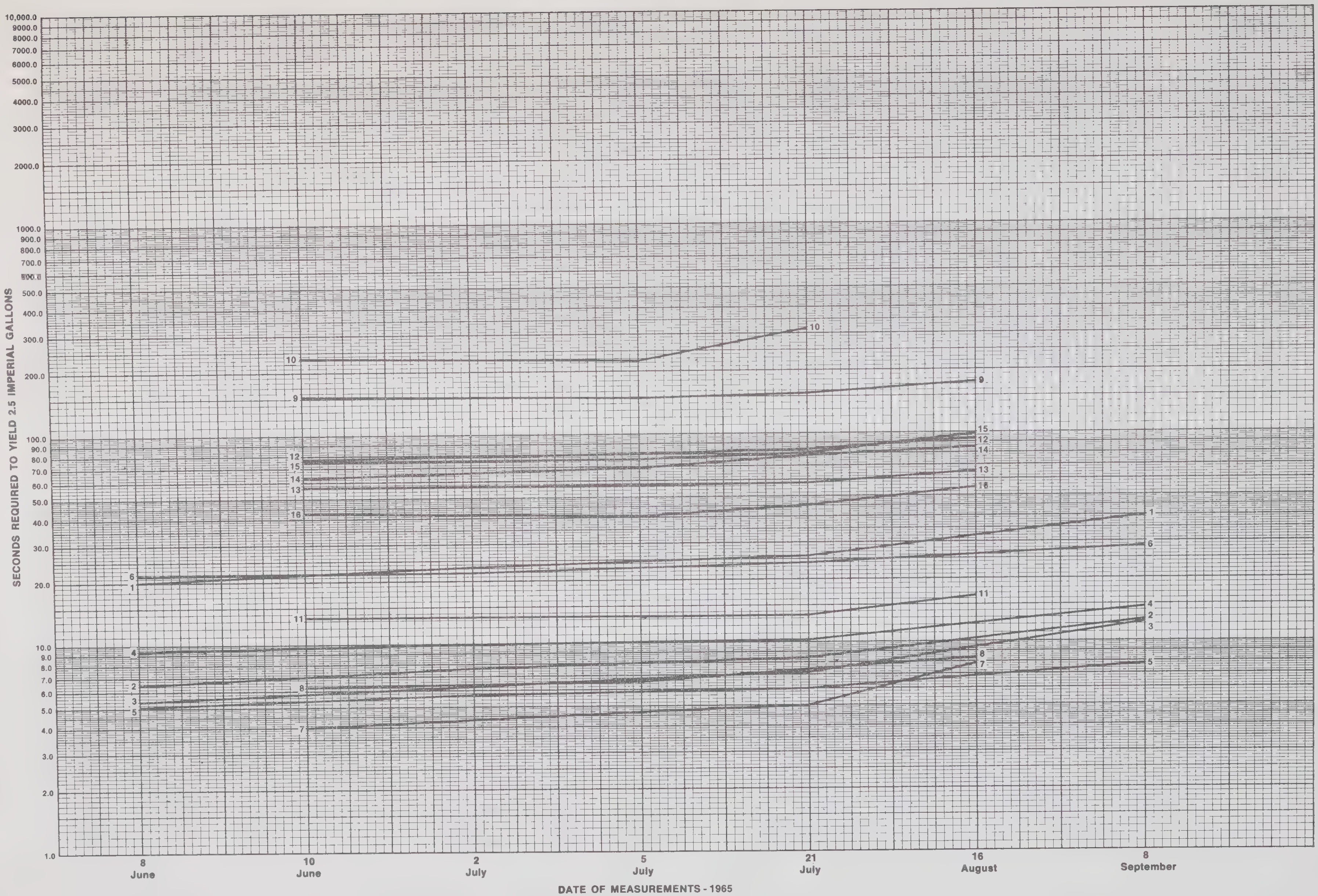

Figure 9 Graphical presentation of flow study measurements at Matlock, Manitoba

Table 1. Flowing wells – Matlock, Manitoba, 1965. Flow study

Well No.	‡ Elevation A.S.L.	Depth of Well	Date June-8-65		Date June-10-65		Date July-2-65		Date July-5-65		Date July-21-65		Date Aug-16-65		Date Sept.-8-65		Remarks
			Time* sec.	Temp. °F	Time sec.	Temp. °F	Time sec.	Temp. °F	Time sec.	Temp. °F	Time sec.	Temp. °F	Time sec.	Temp. °F	Time sec.	Temp. °F	
1	719.34	–	20.2	41	–	–	23.4	42	–	–	26.0	41	–	–	40.0	42	
2	721.26	80′	6.4	41	–	–	7.7	41	–	–	8.5	41	–	–	12.8	42	
3	722.00	57′	5.4	41	–	–	6.3	42	–	–	7.2	41	–	–	12.5	42	Chemical analysis #94
4	720.13	55′	9.4	40	–	–	10.0	42	–	–	10.2	41	–	–	14.6	42	
5	719.89	–	5.1	40	–	–	5.7	41	–	–	6.0	–	–	–	7.8	42	
6	718.78	–	21.9	41	–	–	22.1	41	–	–	24.2	–	–	–	28.6	42	From a hose
7	–	50′	–	–	4.0	40	–	–	4.7	41	5.0	40	7.9	40	–	–	
8	–	–	–	–	6.3	41	–	–	6.6	42	7.5	41	8.4	41	–	–	
9	–	50′	–	–	153.1	42	–	–	148.6	–	155.9	42	178.4	42	–	–	
10	–	35′	–	–	237.2	40	–	–	225.0	41	318.2	41	–	–	–	–	Not flowing Aug. 16, 1965.
11	–	–	–	–	13.6	41	–	–	13.4	42	13.6	41	16.7	42	–	–	From a hose
12	–	–	–	–	77.8	42	–	–	80.2	42	84.2	42	94.2	42	–	–	From a hose
13	–	–	–	–	56.9	42	–	–	57.2	42	58.1	42	65.9	42	–	–	
14	–	37′	–	–	62.8	41	–	–	68.6	41	79.0	42	86.2	41	–	–	
15	718.35	50′	–	–	75.0	42	–	–	76.2	42	80.1	42	97.8	42	–	–	
16	718.65	–	–	–	42.8	42	–	–	40.8	42	45.2	42	55.0	42	–	–	

*Time to fill a 2½ Imperial gallon container
‡Lake Winnipeg elevation taken as 713′

probably derive their groundwater from the sandstone of the Winnipeg Formation. As mentioned earlier, the fact that few wells obtain water from this particular aquifer makes it possible for the aquifer to sustain these substantial yields.

SPRING YIELD

In all, 44 springs were mapped during the study. While the incidence of springs is greater on the east side, the flow is larger in those on the west side. Two large springs occur in a discharge area in what is now drained marshland. One of these, Poplar Spring, is in 1-14-2E and the other Blue Spring, is in 8-16-3E. The large volume of water yielded by these springs appears to originate at the contact of the surficial deposits with the bedrock, which in the case of both Poplar Spring and Blue Spring is some 18 to 25 feet below ground.

Sixteen other springs were mapped on the west side. Some of these were originally wells drilled or dug through the clay and later abandoned and left flowing. Over a period of time, the original well hole has increased in size because of the lack of casing or cribbing and for the purposes of this study, the wells are considered as springs.

The flow of Poplar Spring was found to be 2½ million gpd. In the same vicinity, a well in SW 19-13-3E that could be classified as a spring were it not for the fact that it is controlled, yields 1,500 gpm. To drain this low-lying marsh area of surface water fed by these springs, drainage ditches had to be dug. Some idea of the volume of water, both surfacewater and groundwater, produced in this region can be obtained from the fact that the main drainage ditch in Tp. 15, Rge. 3E that drains the area to Wavey Creek has a capacity of over 1,000 cubic feet per second.

There are a few springs in Tps. 17 and 18, Rge. 4E, along the west shore of Lake Winnipeg, but none of these compares in yield with the springs just mentioned.

On the east side, the springs with the largest yields (generally from 50 to 100 gpm) are found in Tps. 13 and 14, Rge. 6E. Two springs in the area yield 500 gpm. Devil's Creek, which flows through this area, would be intermittent were it not for the supply of water from springs discharging into it. The base flow of Devil's Creek consists entirely of groundwater. The yield of the other spring on the east side is only one to ten gpm.

The coldest groundwater encountered in the study (38°F) was in a spring in NE-3-16-8E. This water is assumed to be all snowmelt because the clay and till were covered by a six-foot layer of peat moss which acted as an insulator during the period when melting snow was infiltrating the ground.

FLOWING ARTESIAN WELL YIELD

There are more flowing wells on the east side of the map-area than on the west side. The average yield of a flowing artesian well on the west side, however, is larger (22 gpm as compared to 6 gpm).

The wells are uncontrolled and the flow (over 1½ million gpd) is wasted. When the flow of the 44 springs in the area is added, it is estimated that the total natural discharge of groundwater in the area is between 5 and 10 million gpd. None of this water is used. A flow study of 16 flowing wells was carried out along the west shore of Lake Winnipeg in the vicinity of Matlock. In this area, in Tps. 17 and 18, Rge. 4E, between Matlock and Winnipeg beach, there is a considerable concentration of flowing wells which were believed to respond quickly to precipitation. It was assumed that recharge was not too far away.

The wells used in the study flowed at an average elevation of 7 feet above the level of Lake Winnipeg. The time taken to fill a 2½ gallon container from each well was measured at seven different times during the summer field season. The data are shown on Table 1. Graphic presentation of the results (Fig. 9) shows that, except for a few cases, there was a gradual decrease in the flow of the wells from June to September and that precipitation, either short-duration from thunderstorms or continuous for periods as long as three days, had no effect on the yield of these wells. It was concluded, therefore, that recharge was not close by, as originally believed, but fairly distant, long term and constant. The degree of parallelism among most of the lines in Figure 9 tends to indicate that these wells tap the same aquifer and possibly have the same recharge origin. The aquifer is in fact the till-bedrock (limestone) contact and the average depth of the wells is 50 feet. It can be predicted, on the basis of the data obtained, that the flow of these wells will continue to diminish, in other words the piezometric level will drop, until the following spring, at which time, it should rise abruptly due to snowmelt and the cycle will be repeated.

In summary, groundwater data obtained in the Selkirk area indicates a daily supply of groundwater of between 5 and 10 million gallons, particularly the west side. This is sufficient for industries requiring from one or two million gallons per day. From the groundwater availability point of view, the region made up of Tps. 14, 15 and 16, Rges. 2E and 3E, where large springs occur, would be ideally suitable as a fish hatchery centre. An area with similar groundwater characteristics but lower yield exists on the east side of the map-area in Tps. 13 and 14, Rge. 6E.

Hydrogeochemistry

SEMI-LOGARITHMIC DIAGRAMS

This part of the study deals with groundwater movement in the entire Selkirk area, specifically with the direction of groundwater movement.

At the outset, it should be noted that a piezometric map of the area prepared some years ago (Render, 1965) demonstrated that groundwater from the east side will flow westward towards Lake Winnipeg and the Red River and that groundwater from the west side will flow eastward towards Lake Winnipeg and the Red River. Furthermore, it has been indicated earlier in this report that the hills consisting of glacial outwash form recharge areas while clay plains are discharge areas. These general indications will be confirmed by the hydrogeochemical interpretation of the direction of groundwater movement.

The method used is basically that of Schoeller (1962), expanded by Charron (1969). The data used as a basis for the hydrogeochemical interpretation of the direction of groundwater movement consists of chemical analyses of 94 groundwater samples. Surface water samples were not used in the study.

A diagram of each analysis was drawn on semi-log paper, with the six major ions rCa, rMg, rNa, rCl, rSO_4 and $rHCO_3$ (see footnote [1]) expressed in equivalents per million. The total dissolved solids value (TDS) of each sample is shown on the diagram in parts per million (ppm). The data used to prepare the diagrams for the 94 groundwater samples and the data derived from the diagrams are shown in Table 2. The analyses are grouped according to their chemical characteristics. Plotting of the diagrams is done with the help of a computer using a computer program written by R.A. Freeze (1967).

Considering the diagrams as a whole, four things are obvious. First, most of the diagrams are concave in shape (excluding the rCa and rMg portion). This indicates that the groundwater represented by these samples is in or near a recharge area. Convex diagrams would indicate groundwater in or near a discharge area. Second, the diagrams are either V-shaped or U-shaped. On the basis of the author's experience of the Red River Valley to the south of the Selkirk area, V-shaped diagrams are associated with confined aquifers while U-shaped diagrams are associated with unconfined aquifers. The latter may also be interpreted as groundwater from a confined aquifer but so close to a recharge area that it would resemble groundwater from an unconfined aquifer. Third, considering only the rMg/rCa ratio, the analyses for the western half of the area without exception represent groundwater with an rMg/rCa ratio greater than one. This is true also of the eastern half of the area as far east as a line roughly following the Brokenhead River. This reflects not only the dolomitic limestone character of the bedrock underlying the western part of the area, but also the dolomitic composition of the till above the bedrock. East of the Brokenhead River the rMg/rCa ratio is, with a few exceptions, less than one. From the rMg/rCa ratio standpoint the area can be divided by an imaginary line approximating the direction of the Brokenhead River, which lies slightly west of the sedimentary Precambrian bedrock contact (Fig. 2).

Lastly, nowhere in the area does the groundwater reach the saturation point in sulphate or carbonate, with the single exception of analysis #13 where the groundwater is saturated in carbonate.

INTERPRETATION OF THE DIRECTION OF GROUNDWATER MOVEMENT

A comparison of two groundwater samples taken at the same well 23 years apart demonstrates that the chemical composition of groundwater in a confined aquifer changes little over the years. Sample #90 was taken in 1965 and is compared with a sample taken in 1942 at the same well. The samples were analysed in different laboratories and the results are plotted as a semi-logarithmic diagram (Fig. 13). The results indicate that, even though a relatively large amount of groundwater has been used and is still being used (the location was formerly a Royal Canadian Air Force base and is now a fish packing plant), there is practically no change in the chemical composition of the groundwater.

As mentioned previously, the diagrams showing similar chemical characteristics or identical patterns are

[1] The prefix r denotes that the value is in equivalents per million (epm).

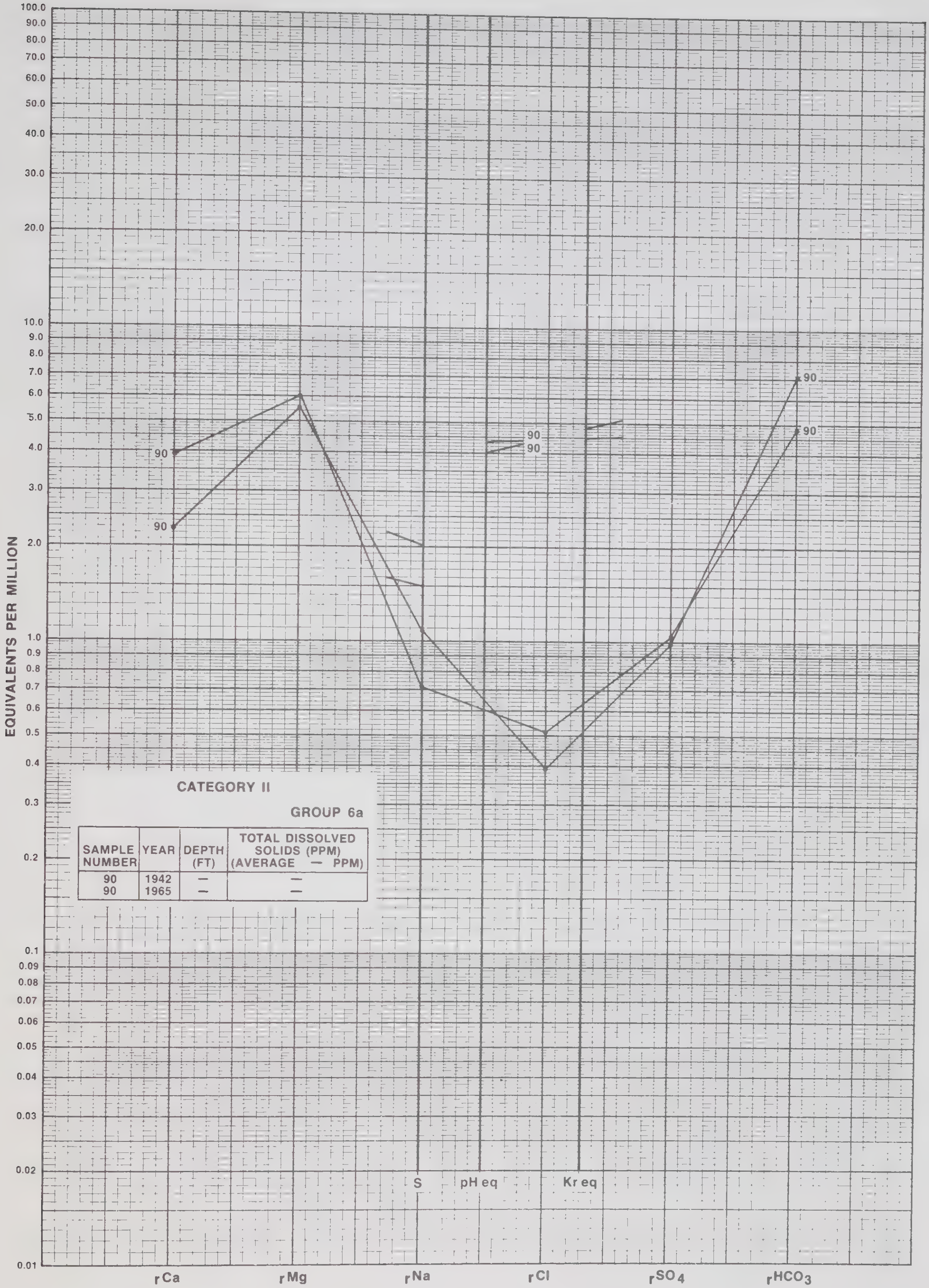

Figure 13 Comparison of two analyses taken 23 years apart

grouped together and this forms the basis for the hydrogeochemical interpretation. Identical samples are brought together as sub-groups (identified as 1a, 1b, 1c, etc.). (In some cases, sub-groups have been further subdivided (as $1b_1$, $1b_2$, etc.)). The sub-groups are brought together into groups and the order of listing is determined by the average TDS value of each sub-group. The groups are classified in three main categories (Category II is divided into two units).

Category I

In Category I, the analyses indicate groundwater from both unconsolidated and bedrock aquifers. In every case, the aquifers are confined. Sub-Groups 1a (Fig. 14) and 1b (Fig. 15) have a V-shaped pattern and low average TDS values (287-301 ppm), indicating groundwater near a recharge area. Group 1c (Fig. 16) is similar except that the rMg/rCa ratio is slightly greater than one and the average TDS value is 425 ppm. Generally, when three adjoining groups with similar patterns show a steady increase in TDS value, as in this case, the groundwater flow is from the group with the lowest TDS value, towards the one with the highest TDS value. This is not here the case.

A group zonation map (Fig. 10) shows that these three groups cover all but two of the hills which consist of glacial outwash deposits, here considered a recharge area. A hydrochemical map (Fig. 11) indicates the existence of the same zone. An isocon map (Fig. 12) however, does not reveal this zone. This can be interpreted to mean that the groundwater flow is not from Sub-Group 1a to 1b to 1c, but that within each group the flow radiates outwards in all directions from each of the seven topographic highs. This is best illustrated by the isocon map (Fig. 12) and by analyses #2 and #3 in Sub-Group $1b_1$, and analyses #5 and #43 in Sub-Group $1b_2$ (Table 2). Sub-Group 1c (Fig. 16), which is subdivided into $1c_1$, $1c_2$ and $1c_3$ (Table 2), illustrates how a change in composition of the bedrock and surficial deposits that form the aquifer through which the groundwaste is flowing, is reflected by a change in the chemistry of the water itself. This is particularly true of analyses #6, #7 and #8 which mark the point at which the groundwater makes its first contact with the sedimentary rocks and enters the clay plain. The diagrams indicate an increase in rNa and rSO_4 values particularly, accompanied by a slight increase in rCl. Analyses #8 and #6 show an rMg/rCa ratio greater than one. This suggests that the surficial deposits are underlain by dolomitic limestone or that the groundwater represented by analysis #8 is under the influence of an eastward flow from the topographic high to the west. The low rSO_4 value of sample #6 may indicate that the groundwater flow is from the hill situated to the southeast in Tp. 12.

Normally, the pattern illustrated by Group 2 (Fig. 17) would indicate a discharge area. The characteristics are the convex pattern with high NaCl and TDS values, positive base exchange index value (rCl value greater than rNa value), and low bicarbonate value. The transition from a recharge area to a discharge area, however, should be gradual, whereas in the case of Group 2, the transition is abrupt.

There is no doubt that the clay plain in which Group 2 is situated is the discharge of possibly a westward groundwater flow originating in the sand and gravel deposits in the hills in Tps. 14 and 15, Rge. 7E. It is possible also that there is flow from the hills in Tps. 16, 17 and 18, Rges. 7E and 8E. The zone formed by Group 2, especially analyses #11, #13 and #39, appears as a pocket (Figs. 10 and 11) and seems to have no outlet. It is a clayey zone marked by many flowing artesian wells. The groundwater is under pressure and rises to the surface in wells (Fig. 4). The clay is a montmorillonite clay which could easily cause base exchange. But the groundwater represented by analyses #11, #13 and #39 is below the clay. Even though the groundwater rises to the surface in wells, it would appear that it does not discharge naturally to the Brokenhead River because the high NaCl concentration encountered in the groundwater is not discernible in the Brokenhead River. If this groundwater, with relatively high TDS and NaCl values, flows underground from this pocket, it would appear to move northward (from samples #11 — #13 — #39 towards sample #21 and finally to the Winnipeg River and Lake Winnipeg). On Figure 11, it appears to flow northward, passing under the zone delineated by Sub-Groups 1a, 1b and 1c. If this were so, the groundwater would have to flow from a zone with a high TDS value (#39, 5107 ppm) to a zone with a low TDS value (#21, 2448 ppm) and it is generally accepted that the reverse is true. It appeared logical, therefore, to divide the zone represented by Group 2 into two pockets.

It was at first thought that the high salt content encountered in the pocket where the TDS value was high was caused by the dissolution of evaporite beds. As steady movement is a basic factor in the hydrologic cycle, it was assumed that the groundwater flow from the pocket was mostly upwards as no resemblance to the patterns making up this group can be found leading outward from the high salt content zone. If the flow were upward (if it were discharging to the Brokenhead River, for example), some chemical phenomenon must be occurring in the transfer of the groundwater; it may per-

haps be moving from one geologic zone to another in such a way that the salt ions are being left behind in the first zone and relatively fresh water finding its way to the second. The best explanation is offered by the phenomenon known as osmosis which was encountered in a similar situation in western Canada (van Everdingen, 1968).

Reverse Osmosis

If two bodies of water, one pure and the other salt, are separated by a particular type of membrane that allows the water through but acts as a barrier to the ions of dissolved salt, some of the pure water will flow through the membrane to dilute the salt solution. The process, called *osmosis*, will continue until the pressure in the salt solution exceeds the pressure in the pure water by an amount known as the osmotic pressure of the salt solution. If a pressure in excess of the osmotic pressure is applied to the salt solution, the direction of the flow is reversed and the salt solution becomes more concentrated while a quantity of pure water passes to the other side of the membrane. This is called *reverse osmosis* (Collier and Fulton 1967).

Reverse osmosis explains the situation in Tp. 14, Rge. 8E. A pocket of salt water is under pressure (artesian pressure) in an aquifer of sand and silt, or of sandstone of the Winnipeg Formation, situated immediately above the granite bedrock. Till or shale above these aquifers act as confining layers and serve the purpose of membranes in concentrating the salt in the aquifer while letting salt-free water move through. After crossing the membrane, the water would follow a lateral path corresponding to the path of the Brokenhead River at the surface.

It is interesting to note that a pressure in excess of the osmotic pressure of the salty solution of the pocket does in fact exist in this aquifer. Where it would require an osmotic pressure of 67 psi to activate the process of reverse osmosis with a salty solution of 5,800 ppm (Sourirajan, 1966), the actual pressure in the aquifer has been calculated at 109 psi. The TDS concentration of the groundwater after it has crossed the shale membrane is 786 ppm (average TDS value of Group 3) as compared to 2,425 ppm (average TDS value of Group 2) before it was subjected to the process of reverse osmosis.

There is some possibility that a southwestward flow from the salt pocket exists, but this is not here considered.

The groundwater represented by Group 3 (Fig. 18) is, therefore, the product of the flow from the salt pocket represented by Group 2 (Fig. 17). The geographical location of the Group 3 zone is shown on Figure 10. Not only are the rNa values of Group 3, and particularly the rCl values, much reduced but there is a reduction in the rSO_4 value (Fig. 18) which in turn brings about a reduction in the Calcium (rCa) value. As the rCa values of the analyses of Group 3 are lower than the rCa values of any other analyses in the entire Selkirk area, it would have been expected that the reverse osmosis process would yield groundwater with a lower rNa content value than was actually the case. What has happened is that a second modifying phenomenon, base exchange, has intervened to replace the calcium ions with sodium ions, thus lowering the rCa and rMg values and increasing somewhat the rNa value.

This appears to be the case particularly with analysis #35 of Group 3, where the well from which the groundwater sample was taken is only 70 feet deep. Another factor that may account for the low rCa and rMg values in Group 3 is the fact that the aquifer is sandstone of the Winnipeg Formation. In the author's experience, this has in the past explained satisfactorily the incidence of these very low rCa and rMg values in groundwater.

The direction of groundwater movement from the salt pocket (Group 2) can be traced by studying the trend of the ions in the semi-logarithmic diagrams for Groups 2 and 3 (Figs. 17 and 18). Starting with the highest TDS value, which is that of analysis #39 and moving in a northwesterly direction (Figs. 10 and 11) towards analysis #15 (Fig. 18), it can be seen that the NaCl value has dropped considerably. While the rNa and rCl values of analysis #15 are considerably lower than the corresponding values of analysis #39 and the sulphate value of #39 is the lowest of the three analyses in Group 3, the rCa and rMg values are the highest. This indicates that the base exchange process at analysis #15 is not in the advanced stage that it was found to be in analyses #33 and #35.

Changing direction and moving from analysis #39 to analysis #11 of the same group, the process seems to be reversed. Although the diagram of analysis #11 is very similar to that of #15, there is no indication of the base exchange phenomenon and the rCa, rMg values are not as low and the rNa value is not as high in sample #11 as in sample #15. It is reasonably certain, therefore, that groundwater movement is not from sample #39 to sample #11, but rather from Sub-Group $1a_2$ to Sub-Group 1c, to Group 2 and finally to Group 3.

In summary, the main characteristics of the diagrams of the Category I are the V-shape of the diagrams themselves at recharge and the fact that the rMg/rCa ratio is almost always less than one while the rNa/rMg

ratio is less than one at recharge, but greater than one from that point on. The diagrams of Category I indicate that recharge takes place at Hills 1 to 7, as illustrated in Figures 3, 10 and 11.

Very little information is available on groundwater flow on the area east of the line of hills. It has been established, however, that the flow is generally eastward towards the Winnipeg River (Category III, except samples #9 and #16).

West of the line of hills, the flow is generally westward. From Hill 1, groundwater flow in sand and gravel zones at the till-bedrock contact is westwards towards analyses #6, #7 and #8. Some of the flow may then continue southwestward, but most is diverted northward towards the salty zone of analyses #11, #13 and #39. A granite bedrock high in Tps. 15 and 16, Rges. 8E and 9E diverts the flow northwestward towards analyses #15 — #33 and #35, following approximately the same path as the Brokenhead River follows on the surface. The chemistry of the groundwater is changed by the two modifying phenomena of reverse osmosis and base exchange. The granite bedrock high mentioned above diverts the westward flow from Hill 2 northwestward towards analysis #21. The westward flow from Hills 3, 4, 5, 6 and 7 is in the direction of Lake Winnipeg.

Category II

The characteristics of the diagrams in the groups and sub-groups of Category II are the U-shape of the diagrams themselves, and the fact that, with the exception of Sub-Group 1a, the rMg/rCa ratio is greater than one and the rNa/rMg ratio less than one, except for analyses #51 and #54.

To begin with, these three groups are related to Hill #8 (Figure 2) and groundwater movement is therefore controlled by that topographic high. The U-shaped diagrams reflect the closeness of the groundwater to the recharge area. The rMg/rCa ratio value of Group 2 reflects the high calcium content in the surficial deposits and in the bedrock (possibly limestone) at that particular elevation (800 feet a.s.l.) on the western slope of Hill 8.

The area of recharge associated with Hill 8 is approximately 30 square miles and the average annual precipitation is 20 inches. Taking into account the sand and gravel nature of the ground and the relatively low water table, it can reasonably be assumed that 50% of the precipitation will infiltrate the ground. On this basis, the annual volume of groundwater radiating in all directions from Hill 8 is approximately 30,000 acre-feet.

The presence of Hill 8 blocks the westward flow of groundwater originating in Hill 1. There are two reasons for this. First, the geological make-up of Hill 8 (thick glacial deposits with gently sloping sedimentary bedrock) makes Hill 8 a substantial barrier, and second, the head developed by the eastward flow from Hill 8 exerts pressure on the westward-flowing water from Hill 1. The net effect is to divert this westward-flowing water north and south.

Analyses #10 and #14 of Sub-Group 1b (Fig. 20) represent the type of groundwater flowing eastward from Hill 8. Most of this groundwater is discharged in flowing wells in the vicinity of Ladywood (Fig. 4). The remainder continues to flow eastward, mixing with the salt zone in Tp. 14, Rge. 8E before turning north (Figs. 10 and 11). In the case of analysis #10, some of the flow may be directed southerly. Sub-Group 1b would appear to be the logical place for analysis #12, but for reasons that are not apparent, it does not quite fit. It is obvious, however, that the rNa and rSO_4 values of analysis #12 are not far removed from the values which would make it compatible with the other analyses in Sub-Group 1b, and for that reason, analysis #12 has been included in this sub-group.

Sub-Group 1a (Fig. 19) marks the beginning of the westerly flow originating in Hill 8. The analyses in this sub-group, while they have U-shaped diagrams, resemble somewhat the V-shaped diagrams of Sub-Groups 1a and 1b of Category I. Even the rMg/rCa ratio is less than one, but this is the last time this occurs.

In Sub-Group 1c of Category II (Fig. 21), the rMg/rCa ratio is greater than one and the indication is that the groundwater flow within this sub-group is from $1C_1$ to $1C_2$ to $1C_3$.

It can be seen, therefore, that groundwater flow radiates in all directions from Hill 8. The flow is predominately westerly, but there is also southerly and northerly flow. The discharge area for the northerly and northwesterly flow is the Red River delta and Lake Winnipeg. Not all westerly flow continues as groundwater. A considerable volume is discharged at the surface as springs and, as mentioned earlier, forms the largest part of the base flow of Devil's Creek. Without groundwater discharge, Devil's Creek would be dry for most of the year.

Group 2 (Fig. 22) closely resembles Sub-Group 1c except for the lower-than-normal rCa values of the former. This cannot be explained by base exchange as there is no appreciable rNa increase shown by the patterns. It is assumed, therefore, that the flow may be local flow. The recharge area of the Group 2 zone, as indicated by analyses #58, #89 and #91, could be the till lens trending north-south as shown on the infiltration map (Fig. 1). To be more precise, for analyses #89 and 91 it is probably the gravelly lenses in the till located on the western and southern edges of Tp. 16, Rge. 4E. In

the case of analysis #59, the exact local recharge location is not apparent.

Analysis #82 is geographically separated from the other three analyses in the group; the patterns however are very similar. Assuming local recharge, an inspection of Figure 1 shows that a large gravelly area exists only one and a half miles west of the point at which sample #82 was collected. The local flow indicated by Group 2, therefore, is easterly.

To the south of the zone delineated by Group 2 (Fig. 10), there exists Group 3 (Fig. 23) where the flow is derived from three deep wells in or near the town of Selkirk. Two of these wells are municipal and one industrial. The convex pattern displayed by the analyses of Group 3 suggests groundwater that has left the recharge area. Group 3 has retained an rMg/rCa ratio very similar to that of Group 2. The stratigraphic logs of the Group 3 wells, however, indicate that most of the groundwater represented by this group is probably derived from the Red River Formation where the aquifer zone or zones would be mostly dolomitic. The wells are situated close to the Red River which not only divides the Selkirk area topographically into two parts but also marks the divide between the surface and possibly the groundwater flow. The question, therefore, is where does the groundwater that flows to the three deep wells of Group 3 originate.

This question would be easier to answer if information were available on the area east and west of the three wells. With the information available, however, it was deduced that the direction of groundwater flow at a depth of 250 to 300 feet in the vicinity of Selkirk is from east to west and possibly southwest. The basis for this is as follows. From Hill 8 west to the Red River, there are no analyses with TDS values higher than those of analyses #50, #57 and #54 (average TDS 795 ppm). West of the Red River, however, higher TDS values (analyses #56 and #57) do exist, even though the wells which these analyses represent are much shallower than the three wells at Selkirk (65′ compared to 285′). Previous studies (Charron, 1969) show that higher TDS values exist to the southwest. It is assumed, therefore, that Hill 8 is the recharge area for the groundwater encountered in the three deep wells at Selkirk and that, although there may be some flow westward from this point, most of it flows southwestward. It is interesting to note that the rMg/rCa ratio for Group 2, where the wells are much shallower than those of Group 3, is very close to the corresponding ratio for Group 3, indicating that some recharge may occur from directly above. This confirms the author's belief that recharge is always much closer at hand than it is generally assumed to be.

The foregoing flow analysis referred to groundwater at a depth of between 250 and 300 feet. The westward groundwater flow from Hill 8 in the dolomitic limestone of the Red River Formation at a somewhat higher horizon (between 25 and 100 feet) moves through analyses #28, #30, #26, #31, #32 to #52 and #53. From this point, at the Red River, flow continues to Group 4(Fig. 24). Only analyses #87 and #88 of Group 4 are here considered. The U-shaped pattern of Group 4 resembles that of Group 1c, the difference being due to the higher rNa, rCl and rSO_4 values of Group 4. Analysis #78 has been placed with this group because of the pattern similarity. However, it has nothing to do with this westward groundwater flow that is now being discussed.

The groundwater flow continues from Group 4 (Fig. 24) to Group 5 (Fig. 25) and this is the ultimate discharge area for the westward flow originating in Hill 8. At this point it meets the groundwater flow from the west.

As the groundwater flow moves westward from Hill 8, the average TDS value of each group increases from 237 ppm in Group 1a to 450 ppm in Group 1c, to 767 ppm in Group 4 (which could almost include Group 3), and finally to more than 1200 ppm in Group 5. This is shown on the isocon map (Fig. 12).

With the exception of the Winnipeg River area of the main eastern recharge zone, the east side of Hill 8 and the zone represented by Group 2, the direction of groundwater flow has so far been westward. For the remaining groups this trend will be reversed and flow will be generally west to east.

On the west side of the Selkirk area, there is a main recharge zone defined by the large HCO^-_3 zone well indicated on Figures 10 and 11 by Groups 6 (Figs. 26 and 27), 7 (Fig. 28) and 8 (Fig. 29). The presence of this zone is confirmed by the isocon map (Fig. 12). The patterns displayed by the analyses of this large recharge zone are very similar to those of Group 1c in the recharge area attributed to Hill 8. This is particularly true of Group 6 (Figs. 26 and 27) which has not only a U-shaped pattern but an average TDS value very close to that of Group 1c (430 ppm (6), 456 ppm (1c)).

Groundwater flows in two directions from this recharge area, eastward and westward. The topography suggests that groundwater movement would be west to east along the north-south axis of the area, and to some extent this is true. It seems, however, that there is a tendency for the groundwater to flow in a southerly direction, especially in the northwest part of the map-area, under the influence of a piezometric low that exists in Tps. 15 and 16, Rge. 1E. This piezometric low induces the groundwater to flow from Tps. 17 (sample #79) and 18 (sample #63) Rge. 2E, southeastward to Tp. 16, Rge. 3E (samples #81, #83, #84, #85 and

#86). From here, it continues eastward to Lake Winnipeg and southeast towards Tp. 15, Rge. 4E (samples #87 and #88).

In the southern part of the recharge area, some of the groundwater flows south from analyses #71 and #72 (Fig. 10), but in Tps. 14, 15 and 16, the flow is eastward. A large part of this eastward flow is discharged at surface, under natural conditions as springs and artificially as flowing wells. Some eventually reaches the $SO_4^=$ + HCO_3^- and Cl^- + $SO_4^=$ zone (Fig. 11) to mix with the groundwater flow from the east.

The pattern of analyses #56, #57 and #66 of Group 5 (Fig. 25) is characteristic of water mixtures in that the six ions of the sample do not display any particular characteristic resulting in almost a straight line. The relatively high salt value of the three analyses is attributed mainly to concentration.

From this discharge area, the groundwater flows to Netley Creek and Wavey Creek and on to the Red River and Lake Winnipeg.

A piezometric map (Render, 1965) shows that groundwater flows in an easterly direction along the western margin of this area. The hydrochemical approach used here shows, however, that somewhere along the line between Rges. 1E and 2E, there is a reversal of flow. It would appear from the diagram for Group 7 (Fig. 28) that the groundwater represented by analyses #75 and #76 could flow either east or west. If the criterion of TDS value is used, analysis #70 indicates that the flow must be southwestward.

The semi-logarithmic diagrams for Group 7 clearly indicate the nature of the bedrock geology. An increase in magnesium of one or two equivalents per million is noticeable in analyses #70 and #75; this is not the case, however, in analysis #76 of the same group. This indicates that the groundwater in Rge. 1E flows through the Interlake or Stonewall Formation which is predominantly dolomitic. The other two formations (Red River and Stony Mountain) through which the groundwater of the previous groups flowed, consisted of shale limestone and dolomitic zones or strata. It appears reasonable to assume, therefore, that there is a westward flow from the main bicarbonate zone to the sulphate zone in Rge. 1E (Fig. 11). The isocon map (Fig. 12) and the group zonation map (Fig. 10) substantiate this. The HCO_3^- + $SO_4^=$ zone represented by Group 8 (Fig. 29) is relatively high in sulphate, due possibly to the red shale formation encountered at the bedrock contact, especially in Tps. 17 and 18. This formation resembles closely the red shale of the Amaranth Formation.

In the northwest part of the map-area, there is another area of groundwater flow. It originates in the bicarbonate zone (Fig. 11) in Tp. 18, Rge. 2E and for this reason is included in Category II; it is, however, classified as Unit B of this category and includes Groups 1a and 1b (Figs. 30 and 31). The direction of flow is eastward. The path of the flow is relatively short; the velocity of the flow is probably fairly high if it can be assumed that the nature of the topography indicates a steep hydraulic gradient. This conclusion is strengthened by the low TDS values at the point of discharge on the western shores of Lake Winnipeg which indicate that the groundwater has either travelled for only a short distance or has travelled at a relatively high velocity; they may also indicate a combination of both.

The only area not yet discussed is the extreme eastern part of the map-area bordering the Winnipeg River. Groundwater information here is very limited. Bedrock underlying the surficial deposits is granite and, as shown on Figure 1, bedrock outcrops over much of the area. Granite is a poor aquifer and the groundwater will flow through the till. As the till is basically clayey, the velocity of flow will be low. On the west side of the Winnipeg River the flow appears to originate in the bicarbonate zone (Fig. 11) and from there it flows eastward to the HCO_3^- + $SO_4^=$ zone, represented by the analyses of Category III. Each of the flows involved could be termed local as each originates in a separate topographical high in the bicarbonate zone and then flows slowly to the Winnipeg River.

Although only one sample (#1) was taken on the east side of the Winnipeg River, the pattern appears to be the same. From Hills 2, 4 and 5, the individual flows appear to converge on the Cl^- + $SO_4^=$ zone represented by analysis #21. This analysis is very similar to those forming Group 1d of Category I. From here, the flow appears to be towards the Winnipeg River and Lake Winnipeg. Sample #46, taken along the Whitemouth River, has the high sulphate value characteristic of groundwater flowing in that basin. The high sulphate value gives a relatively high TDS value to the analysis. A high sodium sulphate content is often encountered in groundwaters associated with shales but the relatively high sulphate value encountered in analysis #1 cannot be explained. In previous reports, the author attributed the high sulphate value to the oxidation of sulphides, but this is now considered unlikely. It may be due to anion exchange but there is no proof of this.

Bedrock Control of Groundwater Movement

In general, throughout the eastern part of the map-area, it was discovered that bedrock outcrops often acted as dams or barriers to the groundwater flow, and to this extent it is true to say that the groundwater flow associated with the water table is controlled by the bedrock.

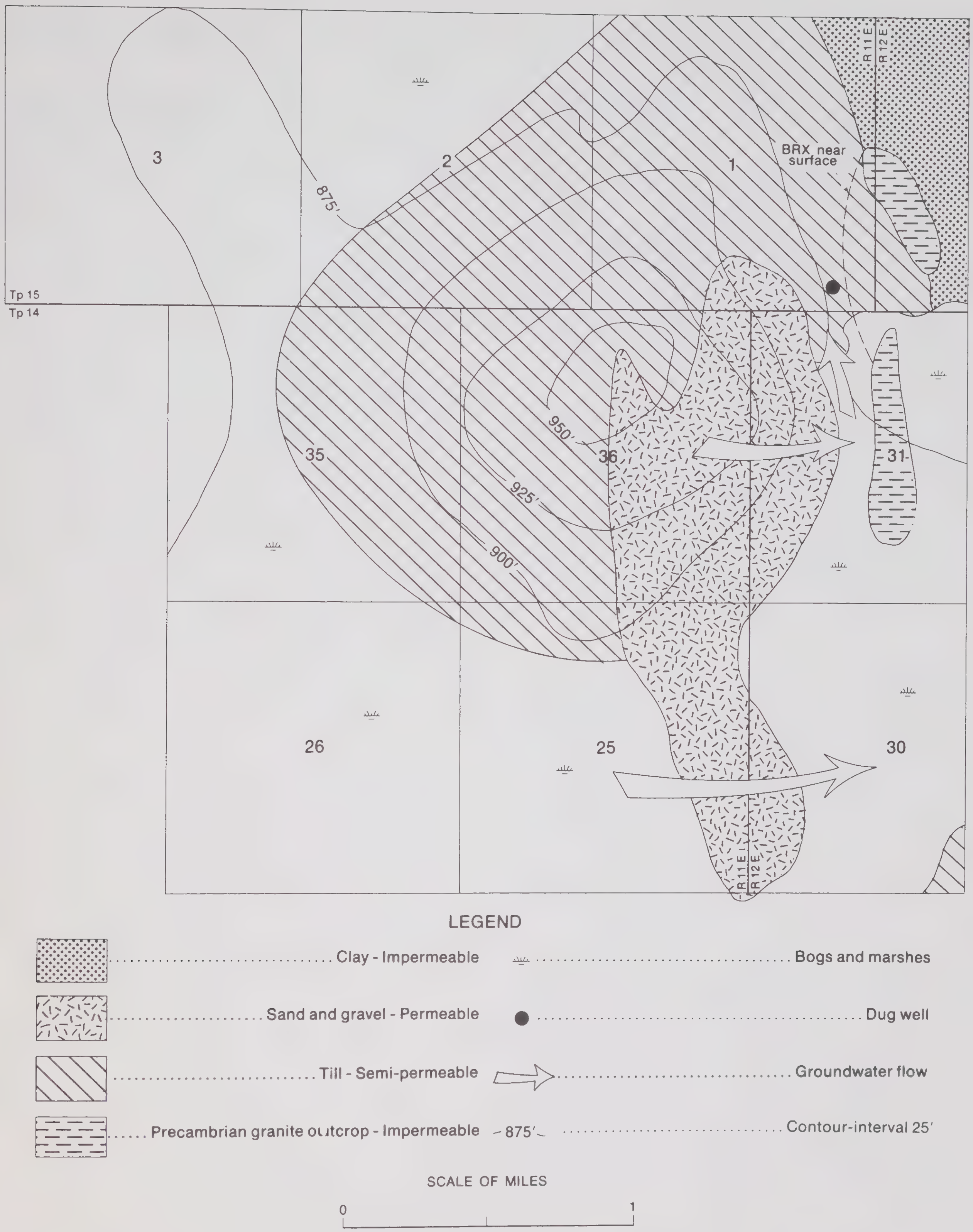

Figure 33 Plan showing effect of granite outcrops on groundwater flow

A good example of bedrock control of groundwater movement occurs in Tps. 14 and 15, Rges. 11E and 12E, where a well in SE1-15-11E only 3 to 4 feet deep supplies all the requirements of a farm from a yield estimated at 50 Igpm. Figure 33 illustrates the effect which the granite outcrops to the east of the main recharge area of sand gravel have on the groundwater flow in the immediate vicinity. The groundwater flow from the topographic high should be easterly but because of the two granite outcrops east of the topographic high, which are associated with a bedrock high underneath a thin mantle of till, the main flow at the base of the recharge area is northward, supplying the well that is used by the farm in Section 1.

Summary

There are three main areas of groundwater recharge in the Selkirk area. These are the bicarbonate zones, illustrated on Figure 11. Individual groundwater flows originate in each topographic high (Hills 1 to 7) in the large eastern bicarbonate zone. From this zone the volume of westward groundwater flow is much greater than that of the eastern flow. The largest westward flow starts in Hill 1. At the foot of this hill in Tp. 8 the groundwater becomes salty by concentration due to a reverse osmotic process. It then flows northwestward to discharge into Lake Winnipeg.

From the central bicarbonate zone located at Hill 8 groundwater flows in all directions. The westward flow, however, is the most significant. Along the course of the westward flow, a considerable amount of natural discharge occurs in springs and as base flow to Devil's Creek. Some of the westward-flowing groundwater continues beyond the Red River to a discharge area in Rges. 3E and 4E. Part of this westward-flowing groundwater is assumed to flow southwestward.

Three main flows originate in the large western bicarbonate zone; one flows west, one south and one east. Of these, the eastward flow is the most important. A large volume of the eastward flow discharges as springs at approximately the 775-foot contour. The remainder flows into the discharge zone in Tps. 13, 14 and 15, Rges. 3E and 4E, mentioned in the previous paragraph. Groundwater from this zone is discharged into Netley Creek and Wavey Creek, to the Red River and eventually Lake Winnipeg.

Determination of Groundwater Movement by Dye Tracer

During the summer of 1965, two projects using dye tracers were carried out at two different localities in the Selkirk Area. The projects are referred to as the Tyndall project and the Poplar project. The purpose was to use dye tracers to determine the direction of groundwater movement and the velocity at each location. The methods used were simple and the results surprisingly good, especially at the Tyndall project.

At the Tyndall project, natural flowing wells were used as extraction wells, while at the Poplar project, a spring known as Poplar Spring was used as the extraction well. Two vegetable dyes, sodium fluorescein and rhodamine B were used as tracers.

The Tyndall project is in a flat, till plain underlain by limestone, eight miles east of the Red River at an elevation of approximately 760′ a.s.l. The Poplar project is almost due west of the Tyndall project and about 15 miles west of the Red River at an elevation of approximately 760′a.s.l. It is in a flat clay plain underlain by limestone.

The main difference in the two experiments is the means employed to trace the dye. At the Tyndall project, a number of flowing wells were drilled. One of these was selected as the injection well and its flow was stopped; the other wells, which were flowing continuously, were used as extraction wells and it was anticipated that the dye placed in the injection well would appear at one or more of the extraction wells. At the Poplar project, there was only one extraction well, a large natural spring known as Poplar Spring. Wells were drilled around the spring and each in turn was used as the injection well. The expectation was that the dye injected in these wells would appear in the spring, depending upon where the injection well was situated in relation to the spring and upon the direction of groundwater movement.

Natural flowing wells and springs were used as extraction wells for the following reasons:

1. The necessity for pumping is eliminated at the extraction well.
2. Only a small amount of dye need be injected in the injection well.
3. The aquifer system is considered to be in its natural state, with the flow from the extraction wells depending on the head at recharge. The natural flow, therefore, becomes constant after all the wells have been drilled and a new groundwater equilibrium reached in the aquifer.

At the time these two projects were carried out, the chemical analyses for hydrogeochemical interpretation of the direction of groundwater movement in the Selkirk area, as discussed earlier in this report, were not available. Without the benefit of these analyses, it was deduced, mainly from the topography, that the direction of groundwater flow at the Tyndall side would be southwesterly and at the Poplar Spring site, southeasterly.

TYNDALL PROJECT

The site chosen for this experiment was NW-35-13-6 east of the Principal Meridian, four miles north and one mile west of the town of Tyndall, Manitoba. The site was chosen for four reasons: it is in a zone of flowing wells; groundwater can be obtained close to the surface (average depth 18 feet); groundwater flow is along a bedrock contact; and the hydrogeology can be easily interpreted.

Hydrogeology of the Site

The recharge area supplying the groundwater to the flowing wells at the test site is believed to be the high sand and gravel ridge to the east of the site referred to in this report as Hill 8 (Fig. 34a). The surface of the land at the test site can be considered flat as the slope is less than five feet per mile. The elevation is some 80 to 90 feet lower than the highest point of Hill 8. The surficial deposits at the site are underlain by the limestone of the Red River Formation which is encountered at an average depth of 18 feet (Fig. 35). The groundwater is confined by a clayey till layer with an average thickness of 10 feet.

The precipitation entering the sand and gravel on the ridge was believed to flow westward, gradually becoming confined underneath the clayey till. At the site, it flows in a silty layer at the bedrock contact (Fig.

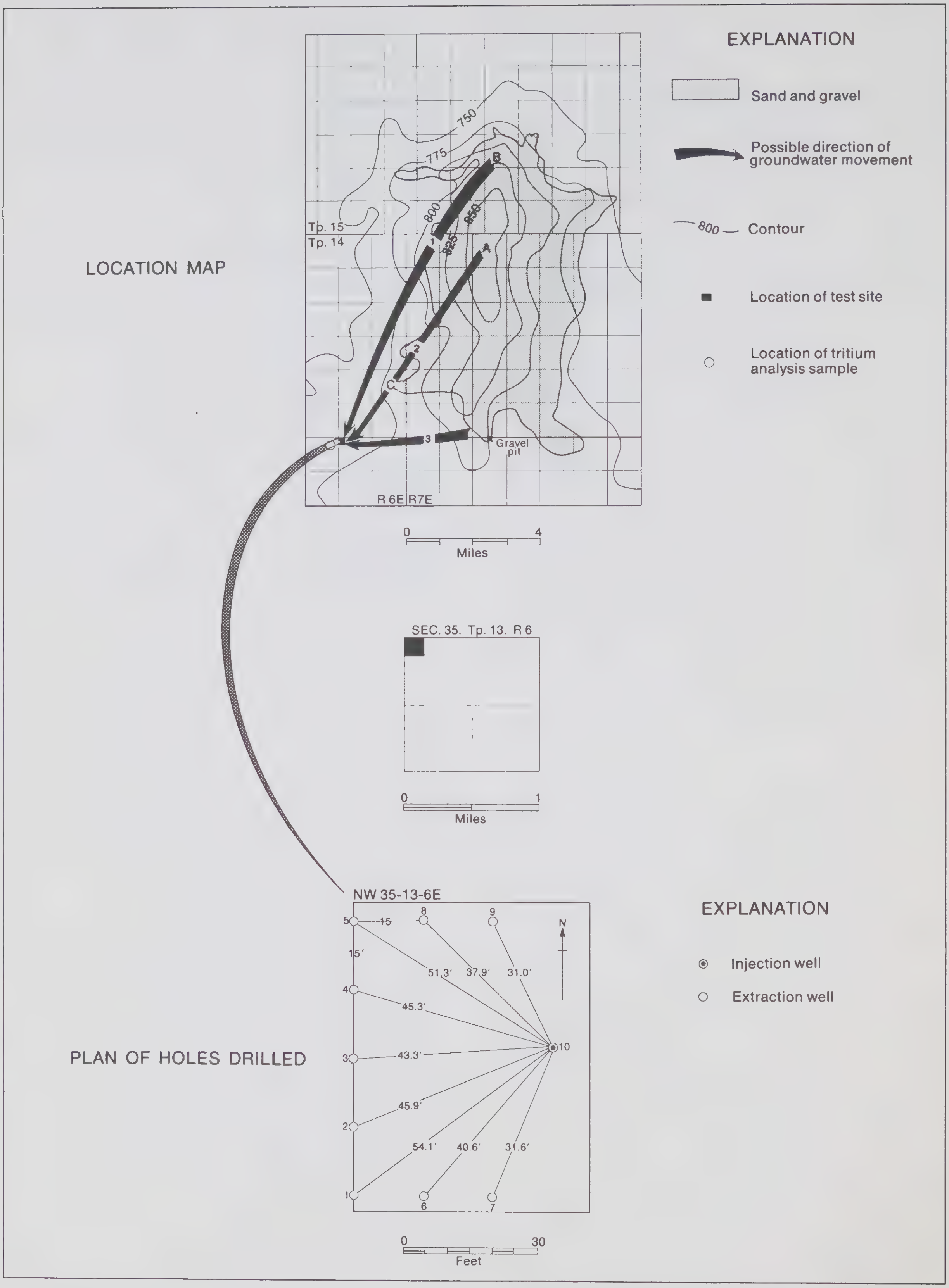

Figure 34a Hydrogeological map of Tyndall Project showing layout of drill holes for dye test

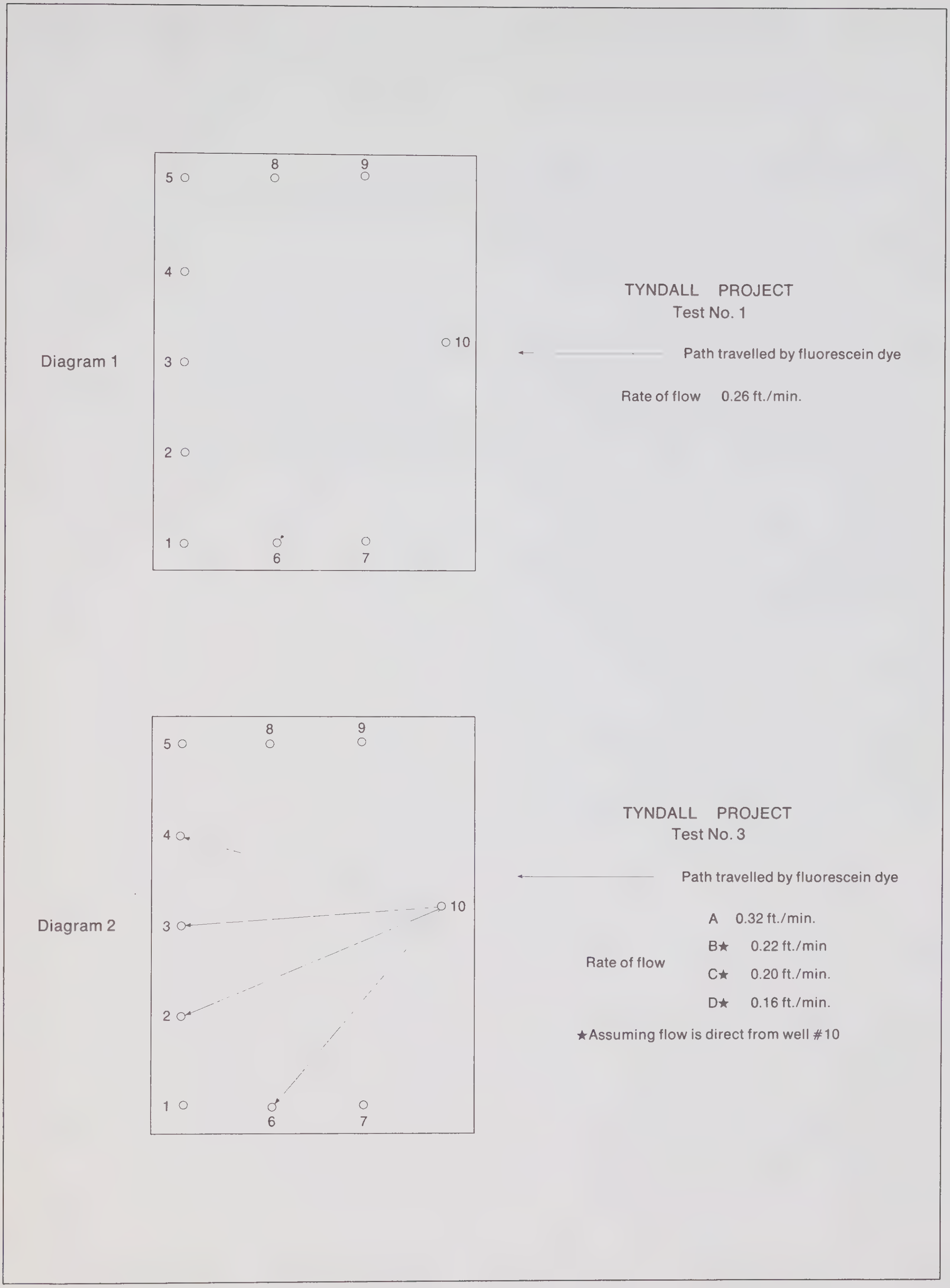

Figure 34b Dye tests, Tyndall Project

35). The bedrock at the contact with the surficial deposits is not solid, but weathered and broken for a depth of about a foot, and it may well be that some or most of the groundwater flows through the broken bedrock rather than through the layer of silt.

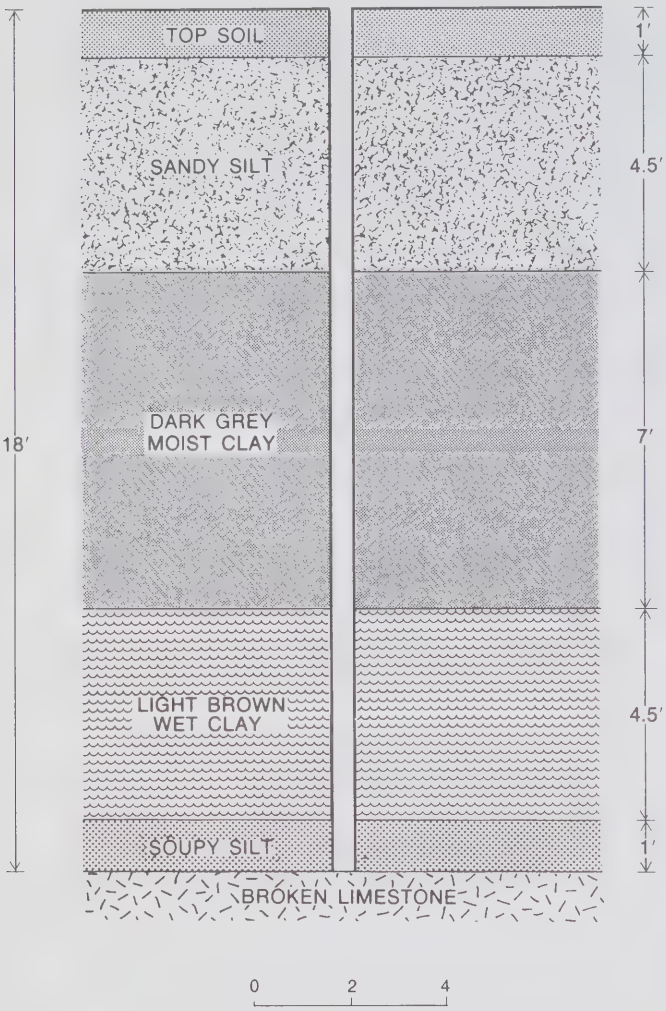

Figure 35 Cross-section of soil layers, Tyndall Project

At the test site, there is a bedrock high that extends throughout the area as far south as the towns of Tyndall and Garson, where the limestone is quarried. The flowing well zone at the site may owe its existence to this bedrock high. If the last statement is correct this would indicate that apart from the thin layer of weathered bedrock, the limestone of this area is only slightly porous or fractured, especially at the top of the formation.

Drilling

Ten 3″ diameter wells were drilled with a portable Minute-Man gasoline-powered auger. The augers were unable to penetrate rock and when bedrock was encountered the drilling was stopped. The wells varied between 15 and 22 feet in depth. Figure 35 is a general cross-section of the site based on the logs of the ten wells. At one foot above ground level, the rate of flow of the 10 wells averaged 23 Igpm. The temperature of the groundwater was constant at 42°F.

The nine extraction wells were drilled 15 feet apart in the shape of a U and numbered in the order in which they were drilled. All were open wells, no casing was used and the wells were left flowing. The injection well (#10) was cased so that the flow could be controlled. Sufficient water to clean out the injection well was allowed to flow before each dye test.

The quality of the groundwater obtained from the wells as determined by Hack kit analyses was considered good. The values of four groundwater tests averaged over the ten wells was as follows: pH, 7.5; Iron (Fe), 0.1 ppm; Salt (NaCl), 37.0 ppm; total hardness, 440.0 ppm.

Dye Tests

Fluorescein dye was used as the tracing agent. Normally fluorescein is not recommended when dealing with an interstitially porous aquifer such as exists here. The fluorescein can be absorbed by argillaceous materials, it reacts with organic matter and ferric oxides, and it can be destroyed by light and weakened by dissolved CO_2 (Schoeller, 1959). It offers the distinct advantages, however, of high solubility and the fact that, at the low concentration of 10^{-7}, it can be easily detected by eye. It was imperative that the wells be thoroughly cleaned after the drilling operation was completed and to make certain that the water remained clear and free of suspended matter, the nine extraction wells were left flowing until the dye tests were completed.

The standard procedure for each test was as follows: Powdered sodium fluorescein, which is brick red in colour, was dissolved in alcohol to form a paste. Approximately two ounces (45 grams) of the paste was then placed in a rubber sheath, and the end closed with a string. The string was tied to the end of the bit of a Central Scientific auger and a 4-ounce lead weight attached to the lower end of the sheath so that it would stay in a vertical position as it was slowly lowered into the injection well. It was important that the sheath should not be punctured as it was being lowered into the well. When the sheath-bit-weight assembly reached the bottom of the injection well at the aquifer level, the sheath was punctured by the pointed end of the bit. The time of puncture was recorded. As there was no groundwater movement inside the casing of the injection well,

most of the dye entered the aquifer and very little diffused upwards.

All that remained was to check the extraction wells for the appearance of dye and record the time at which the dye was noted. Long pyrex cylinders were used to detect the dye. One cylinder was filled with clear water to be used for comparison; the other was used to test for the presence of fluorescein dye in the groundwater.

Test 1

The dye placed in the injection well (#10) appeared in well #6 two hours and thirty-seven minutes later. The distance between well #10 and well #6 is 40.6 feet. This means that the dye travelled through the aquifer at a rate of 0.26 feet/minute. The direction of flow from well #10 to well #6 is S40°W. When the dye first appeared at well #6, the tracer concentration was weak. It gradually increased to maximum concentration and then slowly decreased until it vanished completely. Tracer concentration time curves were not plotted. Approximately four hours lapsed from the time the dye first appeared at extraction well #6 until it completely disappeared. At no time did dye appear at any of the other wells.

Test 2

To verify the results of test 1, a similar test was carried out on the following day. First, injection well #10 was cleaned out to make sure that no dirt had accumulated or had been disturbed by the auger as it was lowered into the well for the previous test, and also to remove the dye that had diffused upwards. When the water flowing from well #10 was crystal clear, fluorescein dye was again put down, using the same procedure. Again the dye appeared at well #6, but this time the time of travel was four hours and thirty-eight minutes, and the rate of flow had dropped to 0.15 feet per minute. After approximately four hours, the dye had completely disappeared from well #6 and as in the first test, it was never seen at any of the other wells. It was deduced therefore that the groundwater had some preference for this particular channel or path between well #10 and #6 and that no diffusion took place, at least none that could be detected by the eye. For additional confirmation, a third test was carried out.

Test 3

Well #10 was again flushed and the dye inserted. Again the dye appeared at well #6, but in the surprisingly short time of two hours and five minutes. The rate of travel was 0.32 feet per minute. As soon as the dye appeared at well #6, well #6 was plugged with cement to determine the direction in which the dye would be forced to travel. Three hours and thirty minutes after the dye had been placed in well #10, it appeared at well #2 (Fig. 34b). After three hours and thirty-eight minutes, it appeared at well #3 and after four hours and forty minutes it appeared at well #4. The rate of flow in the last three cases is not significant because the groundwater may have gone first from well #10 to well #6 and then on to #2, #3 and #4. It is possible also that by the time the dye appeared at well #4 it was coming directly from well #10 because of the plugging of well #6. It is interesting to note, nevertheless, that the groundwater did appear at wells #2, #3 and #4. The dye concentration was not as strong as it had been at well #6, probably because it continued in a southwesterly direction past well #6, and was therefore not available at the other three wells in the same concentration. As was the case with well #6, the dye eventually disappeared from these three wells and was not seen at any of the other holes. It is difficult to understand why the dye did not appear at well #1.

The experiment proves that groundwater flowing in an interstitially porous aquifer has preference (path of least resistance) for certain channels within the aquifer and yet water can be obtained anywhere in that aquifer. This is to say that groundwater could have been obtained from a well drilled anywhere within the area of the test site. The fact that groundwater seems to prefer one path to another may explain the water-witcher's vein hypothesis. It is likely that further tests would have yielded interesting results but saturation of the silty near-surface layer in the piece of land on loan for these tests precluded the possibility of continuing.

Direction and Velocity of Groundwater Flow

The experiment proved that the direction of groundwater movement at the test side is southwesterly (S40°W). This agrees in principle with the hydrogeochemical interpretation of groundwater flow outlined earlier. The difference in the rate of groundwater flow between well #10 and well #6 during the three tests is probably due to a number of causes, none of which can be easily explained. The average rate of flow may be calculated as 0.24 feet per minute or roughly one foot per four minutes. However, this value cannot be accepted as the true rate of flow of the groundwater at the test site. It has to be considered as an exaggerated value because the extraction wells were flowing prior to the beginning of the tests and more importantly, during the tests. Hence the flow of the wells caused a cone of depression that in turn increased the velocity of the groundwater under the influence of that cone in the immediate vicinity of the test site. This velocity increase

is unknown but there is good reason to believe that it is the only factor that affected the natural equilibrium in the aquifer.

Figure 34a shows three possible flow routes followed by the groundwater from the area of recharge towards the test site. Route 1 is the longest at 9.5 miles, route 2 is 7.2 miles and route 3 is 4.0 miles. The average length of the three possible flow paths is 6.9 miles, approximately the length of route 2. In addition, the direction of route 2 is very close to the S40°W direction of groundwater flow obtained by the tests.

The time taken for the groundwater to travel from point A (Fig. 34a) to the test site is based, therefore, on the following data:

1) recharge is the ridge to the east (Fig. 34a),

2) direction of groundwater movement is S40°W,

3) rate of flow is 0.25 feet/minute,

4) distance travelled by the groundwater is 7 miles.

The time required for the groundwater to travel from point A to the test site is calculated to be 102 days. As previously mentioned, no tracer-concentration-time plots were made, but assuming that there was no absorption of the dye during the test, such a curve would be symmetrical. Therefore, as it took approximately four hours for the dye to vanish completely from well #6 from the time it first appeared, a two-hour time limit could be taken as the time of maximum tracer concentration at extraction well #6. Two hours can therefore be added to the flow time of the groundwater. Using the same factors as before but changing the rate of flow value to 0.14 feet per minute, the time taken by the groundwater to travel the 7 miles is now increased to 183 days.

Assuming that the velocity of the groundwater at the test site is doubled because of the cone of depression, the travel time of the groundwater from point A to the test site would be increased to 366 days and the flow rate to 100.8 feet per day.

Tritium Analyses

To check the calculated values, four groundwater samples were taken in the vicinity of the test site for tritium analysis. The tritium determinations were done by Dr. R.M. Brown of the Environmental Research Branch, A.E.C.L. Table 3 lists the tritium concentrations obtained in the four samples.

The lowest MRT value of sample #1, which is the closest to the rate calculated by the author, indicates a groundwater flow of 11.7 feet per day *vs.* 100.8 feet per day obtained through the dye tests. The dye tests and the tritium tests were carried out independently so that the data of one method would not influence the interpretation of data in the other.

Therefore, assuming the tritium analyses results to be correct, the effect of the flowing extraction wells would be considerably greater than had been assumed. The nine flowing wells would increase the velocity of the groundwater at the site by approximately 20 times the natural undisturbed rate of flow.

POPLAR PROJECT

Poplar Spring is one of many large springs situated in Tps. 14, 15 and 16, Rges. 2E and 3E (Fig. 36a). The magnitude of the combined discharge of these springs is such that the Government of Manitoba dug a ditch with a maximum capacity of 1,071 cfs to drain the groundwater flowing from the springs. The daily flow of Poplar Spring is 2½ million Igpd. The pool formed by the spring is 70′ by 60′ (see frontispiece) with a maximum depth

Table 3. Tritium analysis results

Sample No.	Location	Depth of Well (ft.)	Tritium Content (TU) (as of sampling date)	Movement rate	*MRT (yrs)
1	SE-3-14-6E	12	262	4260 ft./yr. 11.7 ft./day	6-11
2	SW-2-14-6E	24	85.6	2620 ft./yr. 7.2 ft./day	8
3	SE-2-14-6E	30	4.2	727 ft./yr. 2.0 ft./day	23
4	SW-1-14-6E	—	2.4	1043 ft./yr. 2.9 ft./day	33

*Mean residence time in closed aquifer system.

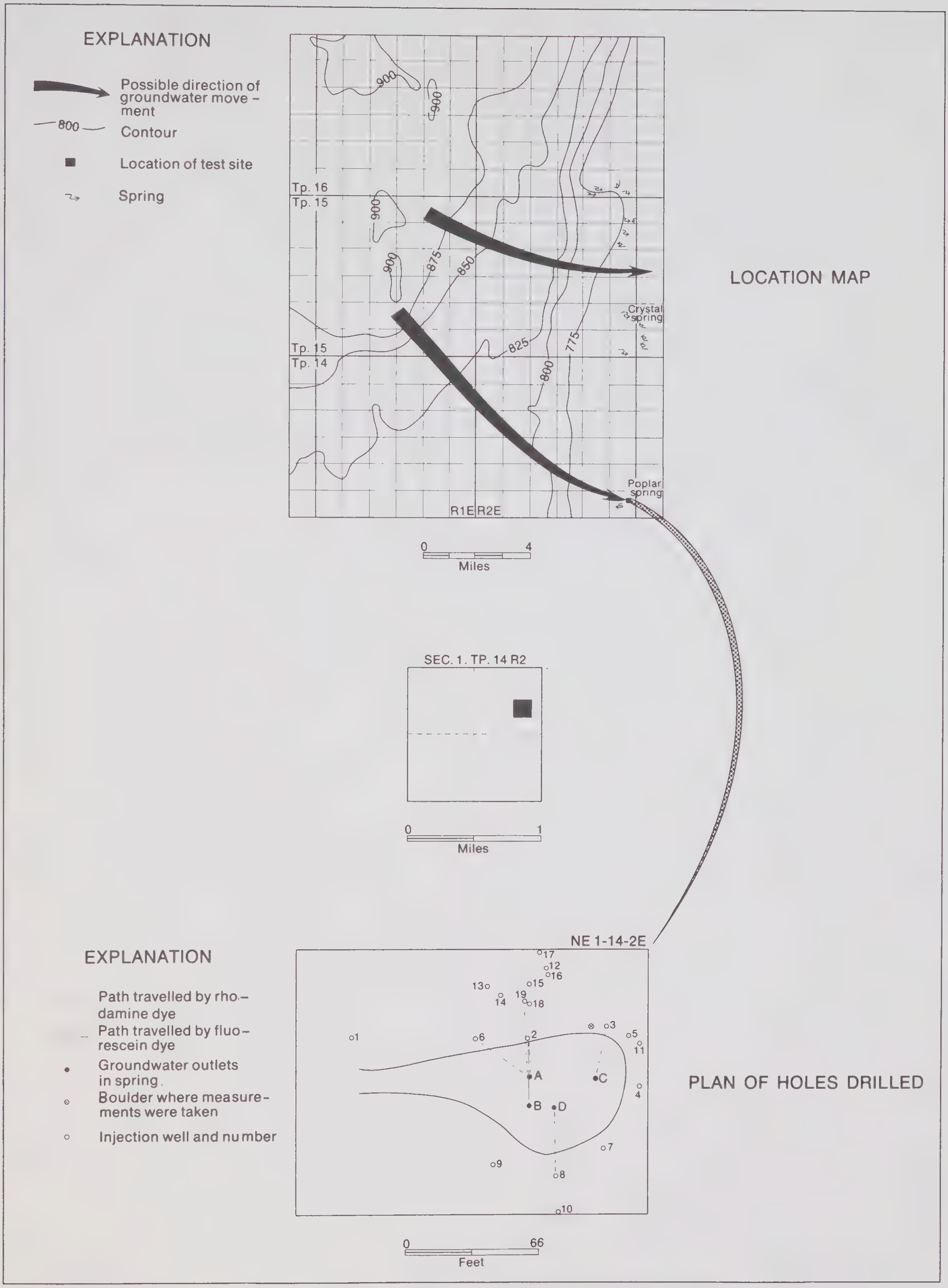

Figure 36a Location map of Poplar Project showing groundwater movement and dye trajectories

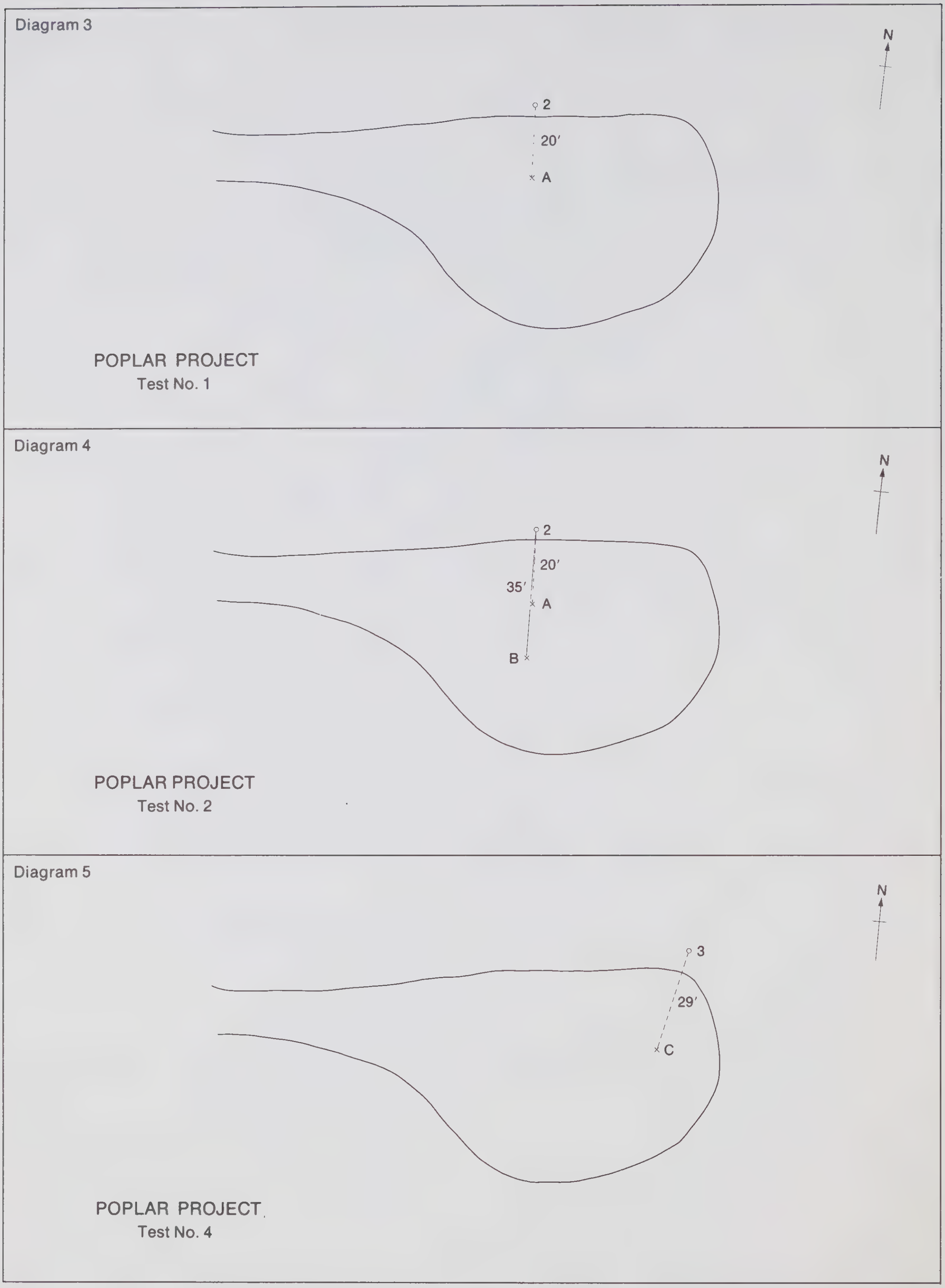

Figure 36b Dye tests, Poplar Project

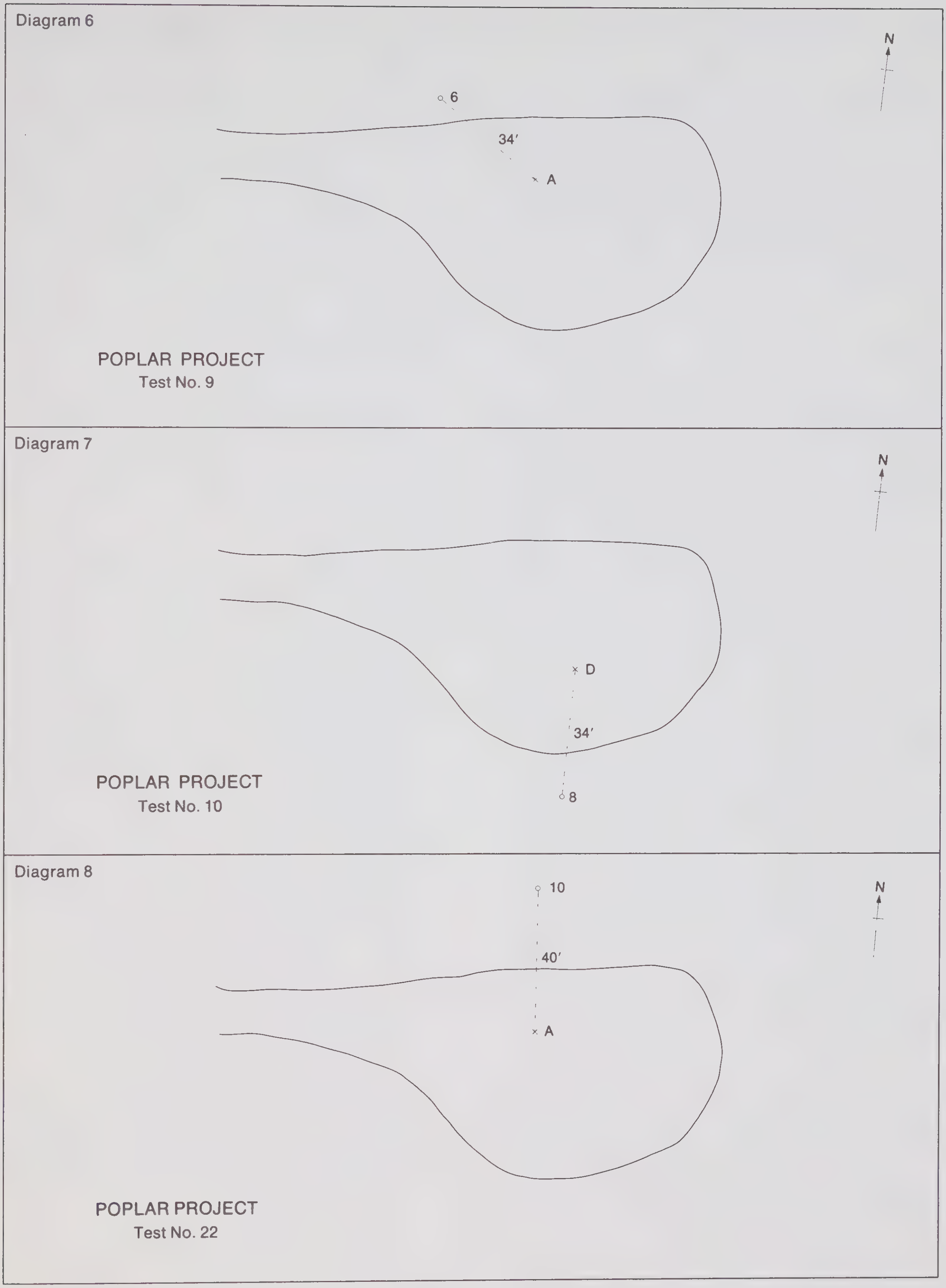

Figure 36b (cont'd)

of seven feet. The pool is fed by four separate springs or groundwater outlets (Fig. 36a).

The location of Poplar Spring is NE-1-14-2E of the Principal Meridian. It is 6 miles east and 1 ½ miles north of the town of Stonewall, Manitoba. Poplar Spring was chosen as the site for a dye-tracing experiment because of its accessibility and the lack of vegetation. All of the other large springs in this area are surrounded by willows that grow as dense bush. Considerable bush clearing would have been involved had any of the other springs been chosen.

Hydrogeology of the Site

The nature of the hydrogeology of the area around Poplar Spring is not as well established as that of the Tyndall project area. At the time of the dye tests, the general direction of groundwater movement in the area, as derived from the topography of the land, was believed to be from northwest to southeast. The exact recharge location cannot be pin-pointed, as at the Tyndall project, but it is believed to be above the 850-foot contour. It was assumed that the groundwater moves southeastward in fractures in the dolomitic limestone bedrock. These fractures appear to end underneath the surficial deposits at approximately the 775-foot contour. From this point, the groundwater flows, still in the same direction, along the till-bedrock contact. At the Poplar Spring site, there is a slight bedrock high. These factors combine therefore, to force the confined groundwater at the test site to rise to the surface when a well is drilled to the till-bedrock contact. The amount of groundwater available at the Poplar site and at the other springs of the area is much greater than that available in the Tyndall area. This would indicate the existence of a larger recharge area. At the Tyndall project the recharge area of Hill 8 is approximately 35 square miles. If the total area of recharge of all the springs on the west side of the Selkirk area is the marshland area north and east of the two Shoal Lakes, the recharge area would be about 100 square miles in area.

Drilling

As at the Tyndall project, the purpose of the tests carried out at the Poplar project was to determine the direction and velocity of groundwater flow at the site. It was anticipated that difficulties might be encountered due to two factors. First, the colour of the water in the pool was green and it was expected that this would make it difficult to detect the faint trace of green caused by the fluorescein dye. For this reason rhodamine B dye was used. Rhodamine B dye is red in colour and can be detected with the naked eye at a concentration of 10^{-9} as compared to 10^{-7} for fluorescein dye. However, the rhodamine dye did not yield good results as most of it appeared to have been absorbed by the clay. It was observed that two ounces of fluorescein would turn the entire pool green whereas a similar amount of rhodamine would colour only a small amount of the water red. The second factor was that the direction of regional groundwater flow might be affected, especially in the immediate vicinity of the pool, because of the large discharge of Poplar Spring itself (2 ½ M Igpd). The large discharge of Poplar Spring could have the effect of drawing the groundwater in the vicinity of the pool toward the spring. In other words, it would act like a large production well with its accompanying cone of influence.

Figure 36a illustrates the location of the nineteen injection wells drilled at the Poplar Spring site. The wells varied between 14 and 26 feet in depth. The deposits intersected were mostly clays, including the rich organic

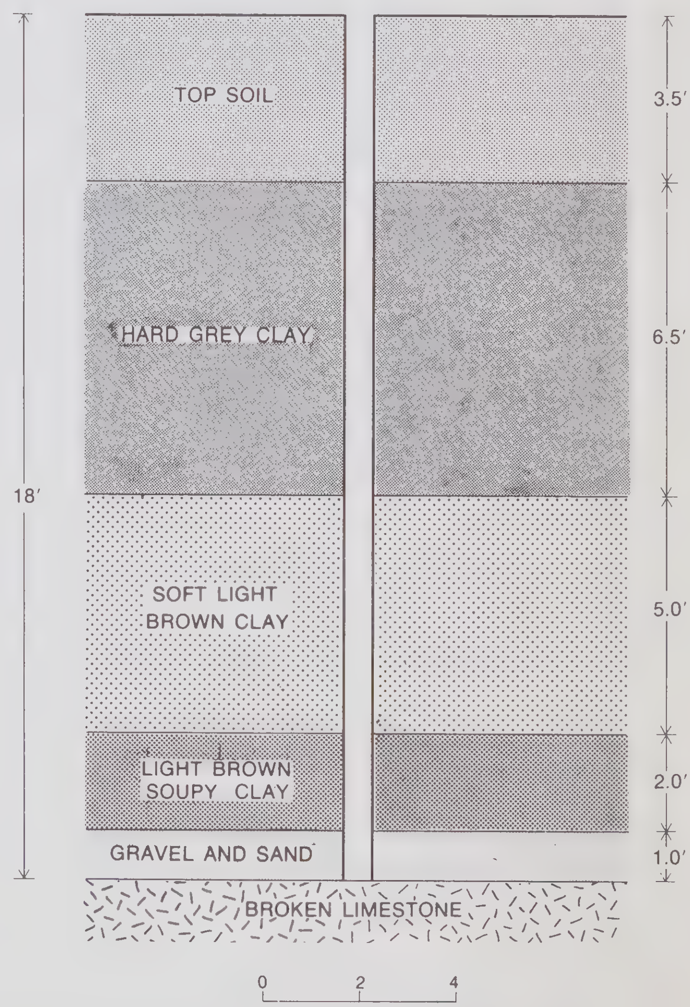

Figure 37 Cross-section of soil layers, Poplar Project

Table 4. Poplar Project S.W.L. readings, well #2 (1965)

Date	S.W.L. (ft.)	Date	S.W.L. (ft.)
July 14	− 0.31	July 28	− 0.72
" 15	− 0.25	" 29	− 0.72
" 19	− 0.31	" 30	− 0.68
" 23	− 0.42	Aug. 3	− 0.75
" 25	− 0.64	" 4	− 0.76
" 26	− 0.68		

top soil at the beginning of each well. Figure 37 is a representative cross-section of the deposits at the Poplar site as derived from the logs of the nineteen holes drilled. The groundwater is encountered in a layer of fine sand and gravel at the broken bedrock-till contact. The temperature of the water was 42°F. The water level in most wells barely reached the level of the ground and a strong natural flow to clean out each hole could be obtained only by digging a trench or canal from the hole towards the pool. In some instances this was difficult because at some time in the past, the spring (or pool) had been dug up and the earth piled in a mound around the pool. This had the effect of raising the ground level especially on the north side of the pool where most of the drilling was to be done. The flow of all the wells except #2 was weak, and flow measurements were taken only at #2.

Well #2 was situated only a few feet from the edge of the pool (Figure 36a) and at that point the ground level was almost the same as the level of the water in the pool. Once the well had cleaned itself out, four-inch casing was used to stop the flow of water from the well. The static water level in the casing rose to about three feet above the level of the surface of the water in the pool. The S.W.L. of well #2 was observed from July 14 to August 4. The measurements were taken from the top of the four-inch casing and these observations are noted in Table 4.

From these observations it is evident that the S.W.L. lowered gradually during the test period.

Dye Tests

The procedure used at the Poplar project to inject the dye in the injection well was the same as that used at the Tyndall project.

Test 1

Well #2 was used as the injection well. The rhodamine B solution injected into the well appeared at point A (Fig. 36b), a distance of 20 feet from well #2, in nine minutes and twenty seconds. The dye travelled at a rate of 2.14 feet per minute (Table 5). The relatively high rate of travel of the groundwater was attributed to the drawing power of the pool on the surrounding groundwater because of the large output of the spring. The dye did not appear at any other part of the pool. One hour and seven minutes after injection, the rhodamine dye had disappeared completely from the pool.

Test 2

Again well #2 was used as the injection well, but this time fluorescein dye was used. The dye appeared at point A, 20 feet distant, in four minutes and fifteen seconds and at point B, a distance of 35 feet from well #2, in ten minutes and five seconds after injection.

From these two time intervals it was calculated that the groundwater travelled at speeds between 3.47 and 4.71 feet per minute. The results were significantly different from those obtained with rhodamine B. This indicates that fluorescein dye can travel faster and further than rhodamine. Surprisingly the fluorescein dye was clearly visible against the natural green colour of the water in the pool and its intensity was much greater than it had been for the rhodamine dye in test #1. Two ounces of fluorescein coloured the entire pool green and it took more than five hours before the pool was clear. The higher groundwater velocity was attributed to the drawing effect of the pool.

Rhodamine dye was used in subsequent tests as fluorescein dye was no longer available.

Test 3

Well #1 (Fig. 36a) was used as the injection well

for this test. The dye did not appear anywhere in the pool.

Test 4

Rhodamine B was injected in well #3. The dye appeared at point C, a distance of 29 feet, in eleven minutes. The speed at which the groundwater travelled was 2.64 feet per minute. The dye did not appear at any of the other four spring outlets in the pool. Again the large discharge of the spring appeared to have had an effect on the velocity and direction of groundwater movement.

Test 5

Well #1 was used as the injection well. The amount of rhodamine injected was three times that used in test #3, but no colouration appeared in the pool.

Test 6

Rhodamine B was injected in well #4 (Fig. 36a) but did not appear in the pool.

Test 7

Dye was injected in well #5 but no colouration was observed in the pool.

The first part of this project was directed mainly towards determining whether the spring drew groundwater from adjoining areas. With this in mind wells #1, 2, 3 and 4 were drilled to cover the north and east side of the pool, on the initial assumption that the direction of flow would be from northwest to southeast. When no colouration from the dye injected in well #4 (test #6) was observed in the pool, well #5 was drilled close to well #3 to see whether the dye would appear in the pool as had been the case when it was injected in well #3 (test #4). The result was negative. For the same reason, well #6 was drilled to narrow the gap between well #1 and well #2.

Test 8

This test was carried out while well #6 was being drilled. The dye was again injected in well #4, but as in test #6 the result was negative.

Test 9

The dye was injected in well #6 and appeared at point A, a distance of 34 feet, in twenty minutes. The rate of travel of the groundwater was 1.7 feet per minute. This test completed the work along the north edge of the pool and proved the drawing effect of the pool on the groundwater. On completion of test #9, wells #7, 8 and 9 were drilled on the south side of the pool (Fig. 36a).

Test 10

Rhodamine injected in well #8 appeared at point D, a distance of 34 feet, in thirty-nine minutes. The rate of travel was 0.87 feet per minute. The colouration at point D was very weak. This may indicate that its appearance is due solely to the drawing effect of the pool because if the natural groundwater flow is from northwest to southeast, dye injected in well #8 should not have appeared at point D. Consequently, well #10 (Fig. 36a) was drilled directly south of well #8 to determine whether the drawing effect of the pool was effective at that distance.

Test 11

Dye was injected in well #9 and the result was negative.

Table 5. Rate of flow of groundwater in dye tests at Poplar Spring Project

Test No.	From well	To Point	Distance (feet)	Rate of flow (ft/min)	Dye used
1	2	A	20	2.14	Rhodamine
2	2	A	20	4.71	Fluorescein
2	2	B	35	3.47	"
4	3	C	29	2.64	Rhodamine
9	6	A	34	1.70	"
10	8	D	34	0.87	"
22	19	A	40	2.00	Fluorescein

Test 12

Dye was injected in well #7 and again the result was negative.

Test 13

Dye was injected in well #10 and again there was no sign of colouration in the pool.

Well #11 (Fig. 36a), was drilled on the east side of the pool to establish that no colouration would appear in the pool from this direction.

Test 14

The dye was placed in well #11 and the result was negative.

It was decided to drill the north side of the pool, far enough away from the edge, so that the pool would not affect the direction of flow of groundwater. Hole #12 was drilled but abandoned as a rock prevented deepening of the well to the aquifer level. Well #13 was drilled north of well #6 (Fig. 36a) to determine whether the dye would appear in the pool as in the case of test #9.

Test 15

Dye was placed in well #13 but with negative results. Wells #14 and 15 were drilled between wells #12 and 13 (Fig. 36a) but a little closer to the pool.

Test 16

The dye was placed in well #14 but with negative results.

Well #16 was drilled east of well #14 and south of well #12 (1) to determine whether dye injected in well #16 would appear in the pool and (2) to determine whether dye injected in well #14 would reach wells #15 and 16, which would indicate that the groundwater flow was easterly.

Test 17

Rhodamine B was placed in well #14 but with negative results.

Test 18

Dye was placed in well #16, again with negative results.

As fluorescein dye was now available, this was used for tests #19, 20 and 21 using well #14; all gave negative results. No test was carried out in well #15 because of the muddy condition of the well.

Wells #17 and 18 were drilled and abandoned as there was no flow and they could not therefore be cleaned. Well #19 was drilled near well #18 (Fig. 36a).

Test 22

Fluorescein dye injected in well #19 appeared at point A, a distance of 40 feet, in twenty minutes. The dye had travelled at a rate of 2.0 feet per minute. This was the last dye test carried out at the Poplar Spring project.

Direction and Velocity of Groundwater Flow

Generally speaking, the dye tests at the Poplar project, although interesting, were not very successful. This was largely because the wells could not be cleaned as effectively as at the Tyndall project. The results at the Poplar site show nothing definite about the direction of groundwater flow. Assuming, however, that the direction of groundwater movement is northwest to southeast and assuming also that the drawing power of the pool on the groundwater is negligible, then the dye tests using wells #1, 2, 6, 12, 13, 14, 15, 16, 18 and 19 (if these wells had been used as injection wells) should have given positive results (colouration of the water in the pool), while similar tests from wells #3, 4, 5, 7, 8, 9, 10, 11 and 17 should have given negative results (no colouration in the pool) (Fig. 36). The only wells in the first group considered clean enough to produce a positive test were wells #1, 2, 6, 14, 16 and 19. Of these only three (2, 6, and 19) did produce colouration.On the basis of the assumptions made, the negative results obtained in the cases of wells #1 and 16 may perhaps be explained as follows. The dye from well #1 could easily have gone undetected had the flow been to the south of wells #9 and 10. Similarly the dye from well #16 could have gone undetected by flowing north of wells #3, 15 and 11. Because of the high velocity of groundwater flow (two feet per minute) indicated in test 22, it would appear that the drawing effect of the pool should have had some effect on the groundwater at well #16 and there should, therefore, have been a positive result. This was not the case. In the case of well #14, there is no easy explanation. The dye tests involving this well as the injection well should have yielded positive results.

Of the remaining nine wells to the east and south of the pool, all should have given negative results, again on the basis of the two assumptions. However, only wells #3, 4, 8, 9 and 10 are considered to have been clean enough for the dye tests. The fact that positive

results were obtained in two wells only helps to prove that the drawing effect of the pool did in fact exist.

If nothing else, these tests prove that the groundwater of a relatively large area around the pool is drained into it. The drawing power of the pool seemed to be greater on the north side than on the south side, which may indicate that the natural groundwater flow is generally north-south. The Poplar tests also indicate that the groundwater appears to prefer certain paths as was indicated also at the Tyndall project.

The average velocity of the groundwater calculated from the six positive dye tests was 2.50 feet per minute (Table 5). This velocity is much too high to indicate normal groundwater flow where the hydraulic gradient is less than 0.1 per cent. The high velocity must therefore be attributable to the drawing effect of the high-discharge (2 ½ M Igpd) pool on groundwater in its immediate vicinity.

SUMMARY OF DYE TEST RESULTS

The Poplar project indicates only tentatively that the general direction of groundwater movement at Poplar Spring is from north to south. No significant values were obtained in determining the true velocity of the groundwater at the same location.

The two projects do, however, illustrate the need for the type of systematic drilling that characterized the Tyndall project and the requirement from extremely clean holes if vegetable dyes such as fluorescein and rhodamine are to be used.

Groundwater Quality

The quality of the groundwater in the entire Selkirk area may, with the exception of three regions, be considered generally good to excellent. The exceptions are the two saline zones found in Tp. 14, Rge. 8E and Tp. 17, Rge. 7E and the area adjacent to the Whitemouth River in Tp. 13, Rge. 11E.

Table 6 illustrates the analytical data obtained for the 94 groundwater samples collected. An average of all the constituents analysed is available at the end of the table and this can be compared in some cases with the recommended standards. It should be emphasized that these analyses are chemical analyses and do not indicate whether a groundwater that is reported to be chemically potable is bacteriologically safe.

Depth, Temperature and Colour

The average depth of the wells from which groundwater samples were obtained for chemical analysis (excluding the springs) was 103 feet. The average temperature of the groundwater was 6.4°C (43°F). The fact that some of the groundwater temperatures appear high can be attributed to the impossibility in some cases of obtaining the groundwater sample at the source (well). The coldest temperature recorded in the Selkirk area is that of sample 38, a spring. This spring occurred in till covered by peat and it is likely that the very cold spring water is the direct snowmelt infiltration kept cold by the insulating effect of the peat. The colour at 6 Hazen units is acceptable (a reading of 5 or less is considered excellent).

pH, Carbon Dioxide (CO_2)

The pH of the groundwater is basic with an average of 8.1. All samples except 13 and 39 have a pH value of 7.0 or greater and even in these two samples the pH value is close to being neutral. It is interesting to note that the pH value of all the samples except one (57) from range 1E to range 6E is greater than 8.0. Most of the groundwater in the area is therefore very near saturation in $CaCO_3$ and in one case it is supersaturated. The average value of 6 ppm of free CO_2 in the groundwater is normal. It was hoped that high CO_2 values might be obtained for samples 74 and 75, for reasons that will be explained later, but this was not the case.

Hardness and Alkalinity

Generally throughout the entire Selkirk area, the groundwater is very hard, averaging 368 ppm total hardness. The hardness is due mainly to Ca and Mg salts except where the salinity of the groundwater is relatively high. This carbonate hardness is given as the alkalinity value and can be termed as temporary hardness. The temporary hardness can be eliminated by boiling the water or by using a water softener. It is true to say that the hardness factor poses the greatest inconvenience in using the groundwater of the Selkirk area. It is interesting to note, nevertheless, that one small region, Rge. 7E in or near the Scantebury Indian Reserve, yields very soft water as illustrated by samples 15, 33 and 35. The softness of the water is due to the combination of the two chemical modifying phenomena of base exchange and reverse osmosis previously mentioned in the hydrogeochemical part of this report. During the course of the study it had been assumed that groundwater obtained from wells represented by samples 33, 34 and 35 would be from the same source and would therefore have the same chemical composition. This was not so. The groundwater represented by analysis 34 is completely different from the groundwater represented by the other two analyses, indicating that it has a different source, probably Hill 3.

Calcium (Ca) and Magnesium (Mg)

The average values of calcium and magnesium as given in Table 6 are 61.5 and 52 ppm respectively. These values are normal considering the dolomitic limestone aquifers that yield the groundwater. Even though the average calcium value is greater than the average magnesium value for the area, it has been demonstrated previously in this report that the Mg/Ca ratio is greater than one in the western part of the Selkirk area.

Sodium (Na) and Potassium (K)

The average sodium value of 68 ppm is well below the maximum allowed. Only in the saline areas is the water too salty for domestic purposes; it is not too salty for livestock consumption. The potassium values are all low and are non-indicative.

Iron (Fe)

The average iron value of 0.8 ppm is greater than the maximum recommended level of 0.3 ppm. It is less, however, than the value of 1.0 ppm recommended for good efficiency with water softeners. The value of 1.0 ppm is exceeded in 25 of the samples, although high iron values in some of those samples are due to iron particles in suspension rather than to iron in solution. Iron filters would reduce the iron content of the groundwater of many of these samples. The fact that 41 samples yield less than 0.3 ppm iron, shows that large regions within the Selkirk area yield groundwater with almost no iron in solution.

Bicarbonate (HCO_3), Sulphate (SO_4) and Chloride (Cl)

In the western part of the map-area, the bicarbonate value varies from a minimum of 300 ppm to a maximum of 500 ppm, again reflecting the dolomitic limestone bedrock underlying that part of the area. In the eastern part, the bicarbonate value has a greater range, with the lowest values observed in the saline zones. The high chloride content combined with the low bicarbonate values is indicative of a discharge area. The average sulphate and chloride values of 125 and 250 ppm, respectively, are below the allowable standard except in the eastern saline areas where they exceed 500 ppm. One of the chemical characteristics of the Selkirk area is the lack of the sulphate reduction phenomenon usually accompanied by H_2S and soft waters.

Fluoride (F)

In general, the fluoride value is lower than the recommended standard of 0.5 ppm. Two regions, however, yield groundwater favourable to the prevention of tooth decay, i.e. a fluoride content between 0.5 and 1.5 ppm. The larger of these regions is on the west shore of Lake Winnipeg and involves samples 59, 61, 62, 71, 92, 93 and 94. A smaller area can be found in Tp. 17, Rges. 8E and 9E and involves samples 6, 7, 8, 9 and 11.

Three high fluoride values are shown in Table 6 and it is no coincidence that they all occur in a zone that yields soft water. It is known that high sulphate values interfere with normal laboratory procedure for determining fluoride and also increase the true fluoride value. The sulphate value in analyses 15, 33 and 35 is not high (less than 400 ppm) except in relation to the TDS value. Also, although the groundwater represented by these analyses is soft, the sodium chloride value is relatively high. There may be a relationship between the high fluoride value on the one hand and the high sodium chloride and sulphate values in soft waters on the other. The author has encountered the same high fluoride phenomenon associated with soft water in previous studies in the St. Pierre area of the Red River Valley, Manitoba. The major difference was that in the latter region sulphate reduction existed along with H_2S in the groundwater.

Nitrate

The average nitrate concentration of 7.7 ppm is within the normal range for drilled wells in confined aquifers. What is somewhat surprising is that of the 94 samples taken, 61 record less than 1.0 ppm nitrate. The largest concentration of nitrate is in the northwest corner of the map-area, as indicated by samples 67, 69, 70, 71, 72, 75 and 76. Of these seven samples, 70, 75 and 76 have positive base exchange indexes as shown on the semi-logarithmic diagrams (Fig. 28). This is unusual in that the groundwater represented by these samples is considered to be in a recharge area. Two explanations are possible: (1) there has been an exchange of sodium ions for calcium and magnesium ions, which would account for the lower than normal sodium value, or (2) the higher-than-normal chloride value relative to sodium may be related to the higher-than-normal nitrate values. In other words, there may exist an anion exchange of nitrate ions for chloride ions. This is the second time in the course of the author's studies that this possibility has presented itself.

Silica

The average silica content of the area is normal under the existing conditions.

Sum of Constituents (TDS) and Conductance

As the two are synonymous for all practical purposes, the term total dissolved solids (TDS) will be used here. Generally, in the Red River Valley, the quality of groundwater has been classified as: excellent water (less than 500 ppm TDS); good water (500 — 1,000 ppm TDS); fair water (1,000 — 1,500 TDS). Of the 94 samples, 66 represent groundwater sources of excellent quality, 20 are good, 4 are fair, leaving only four samples that can be considered as poor.

Percentage Sodium, Sodium Absorption Ratio (SAR)

These values are important in assessing the suitability of the groundwater for irrigation. The relatively

low sodium value (20%) obtained as an average for the area is much below the permissible maximum of 60 percent. Five analyses, however, have sodium values greater than 60 percent. In fact, the groundwater represented by three of these analyses (11, 15 and 21) could be used for irrigation in any case on the basis of the relatively low NaCl content. All but two of the samples have an SAR value less than the recommended figure of 18.

To summarize, the groundwater of the Selkirk area can be chemically classified as being good, potable, cold, clear and hard water with minute amounts of iron and nitrate in certain instances.

Gas Exhalations from Wells

During the course of this study, gas exhalations were observed from wells in Tp. 15, Rge. 1E and vicinity (Fig. 38). These wells are known locally as ''blowing wells''.

Gas exhalations from wells and other sources occur in many parts in the world. CO_2 exhalations from wells in Europe and in Africa (Gevers, 1942) are used to produce commercial CO_2. Although a complete analysis of gas exhalations of the wells in this region has not been made, CO_2 does exist, although not in sufficient quantity to be produced commercially. A short discussion of gas exhalations in the area is included here mainly because of the interesting characteristics of the exhalations themselves. In many instances, when wells are drilled, gas exhalations may occur for a period of several days or for even longer periods extending into years. This is the case in oil fields in Europe and Africa and other parts of the world. In the area under study, the wells were found to produce gas exhalations only with a change in barometric pressure and then only when the barometric pressure changed from high to low. No attempt will be made here to explain the origin of the gas.

The stratigraphy of the area is shown in the three cross-sections on Figure 38. The surficial deposits consist mainly of till varying in thickness from 25 feet to 90 feet. All the wells penetrate the dolomitic bedrock of the Interlake group. None of the so-called blowing wells is less than 80 feet deep and the average is 128 feet. The following is a description of the drilling of a well in NW 20-15-1E. The first 45 feet was till. From 45 feet, the bedrock was dolomitic for a further 80 feet. At the 50-foot level, or just 5 feet into the bedrock, some gas exhalations occurred. Groundwater first appeared at 95 feet but the supply was very limited. At the 100-foot level more gas exhalations occurred and the water previously encountered at 95 feet was no longer in evidence. The main groundwater aquifer was encountered at the 115-foot level. The static water level rose 10 feet to 105 feet from surface. Ever since this well was drilled in 1954, gas exhalations have occurred with a change in atmospheric pressure. It would seem, therefore, that the gas is at various elevations in fractured parts of the dolomitic bedrock.

From the three cross-sections (Fig. 38) it is obvious that the piezometric level of the groundwater in the region where these blowing wells occur is abnormally low. This is illustrated in the cross-sections where there is a comparison with the piezometric level established by Render (1965). Figure 38 shows in plan view the piezometric low in the area where the blowing wells occur. It should be noted also that the groundwater table is indicative of the impermeability of the till at the various localities where shallow wells were dug. The impermeability of the till is reflected also by the many elongated sloughs lying on the till at the surface.

There are two ways in which gas exhalations produced at these blowing wells are used by local residents. First the wells are natural barometers which not only provide good indications of approaching storms but also indicate the intensity of the storm by how hard the wells are blowing. Second, the blowing wells are used by farmers to control the temperatures of milk houses. The temperature of the gas is 60°F and can be used to keep the milk house cool in the summer when the outside temperature is above 80°F and warms the milk house in winter when the outside temperature is below -20°F. It is claimed locally that when these wells are not exhaling gas, they inhale air, but the author did not encounter this phenomenon in the course of the study.

Even though insufficient gas is available for commercial usage the area has one great possibility. Because of the low piezometric surface, the area should be ideal for an artificial recharge study. Actually, the demand for groundwater in this region is not great enough to require artificial recharge but the large amount of water in the elongated sloughs (marshes) to the west (15-1W) and north (16-1E and 1W) could possibly be drained into the dolomitic aquifer where the piezometric low exists in 15-1E. How much unproductive wet land could be made available depends only on the feasability of such an artificial recharge project. If feasable, it would add to the amount of groundwater already available in the Selkirk area.

Conclusions

The Selkirk area can be said to have large amounts of good hard potable groundwater, especially west of Range 7E. The full groundwater potential of the area is far from being used and is in fact lost as natural discharge. The possibility of increasing the supply by artificial recharge exists.

The western part of the area has the largest amount of groundwater of any area studied by the author in the Red River Valley of Manitoba. Where springs occur, groundwater conditions make the area attractive for the establishment of a fish hatchery. This applies also to a lesser extent to the region just north of Tyndall.

The well inventory data compiled in 1964 and 1965 as a basis for this study are on file in the Inland Waters Directorate, Department of the Environment, Ottawa, and will be made available on request.

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